**A FORCE STRUCTURING MODEL FOR A**

**MODERATELY-SIZED NATO COUNTRY**

THESIS

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*"Future lies in the skies."*

*Mustafa K. ATATURK*

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Hakan BAL

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# ABSTRACT

Determining weapon platforms and munitions inventories is of great interest to senior military decision-makers. Because of the increasing cost of weapon systems, and the vital importance of future procurement decisions, senior decision-makers need to select the right balance of systems given limited budgets.

The overall scope of this research is to develop a mathematical model, which aids the decision-makers of a moderately-sized NATO country to develop their future force structure composition. The problem was handled by using some ideas from existing models and by adding some new approaches.

The proposed algorithm determines the optimal force-structure for campaign goals by using linear program to allocate the optimal number of weapon systems and munitions against each target. The algorithm incorporates the procurement decisions of weapon platforms while aggregating many of the details of the campaign theater. By varying the cost of an aircraft and the conditions of hypothetical conflict situations, the decision-makers are provided with a decision support tool for deciding the right mix of weapon systems and munitions. With the solution of a hypothetical conflict scenario, sensitivity analysis is conducted to further analyze the results.

# A PROPOSED FORCE-STRUCTURING MODEL FOR A MODERATELY-SIZED NATO COUNTRY

## I. INTRODUCTION

### 1.1. Background

Planning an air campaign requires the coordination of many predetermined military objectives in the face of limited resources such as aircraft, munitions and budget Limited resources and time must be used effectively to satisfy these objectives. Senior decision-makers must ensure that they have sufficient weapon platforms and munitions to survive a conflict before becoming involved in any such conflict. Sufficient stocks of these weapons and munitions must be in place for timely use in combat. To determine the required stores and mix of such weapons, some evaluation of their use in projected hypothetical theater-level conflicts is required.

In determining the most efficient levels of weapon platforms and munitions stocks in the inventory, the United States Air Force (USAF) has used optimization approaches over the last 30 years or so. However, the USAF's past experience with previous conflict situations has shown there are additional areas that need to be evaluated. This is shown in the following three problems, which cover virtually all questions a munitions optimization must address. These include:

- **The Tradeoff Problem.** What is the effect of having or not having a particular weapon in the inventory?

- **The Allocation Problem.** What is the best way to allocate munitions and aircraft to targets, given a fixed inventory and scenario?
- **The Requirements Problem.** What weapons inventories do we need to meet our warfighting goals for a particular scenario? (Yost, 1996: 1).

Different models have been developed to address these problems, all of which require certain fundamental inputs. First, the models need a scenario, which includes many different target types and some measure of importance or precedence for their destruction. Second, the models require a set of aircraft and a set of munitions, all of which vary in amount and type. Third, the models need data sets to describe the effectiveness of each feasible aircraft-weapon combination against each target type.

Given this information, these models attempt to optimize the allocation of aircraft and weapons into sorties against targets in accordance with some objective function (Yost, 1996:1). Force structure problems have been approached by using optimization to best allocate aircraft and weapons to targets in a particular scenario. Since there is no general agreement on exact formulations of requirements, the objective functions and constraints differ significantly from one model to another. On the other hand, there are many modified versions of a particular model to meet the different needs of small divisions or sub-commands.

### 1.2. Purpose of the Research

Determining weapon platforms and munitions inventories is of great interest to senior military decision-makers. Because of the increasing cost of the weapon systems,

and the vital importance of future procurement decisions, senior decision-makers need to select the right balance of systems given limited budgets. Simply buying the system with the least initial cost may not be effective over the system's entire life cycle. The least expensive purchase item may have high downtime and maintenance cost, or worse; it may have high attrition rate and cause the loss of the most valuable factor in the battlefield: personnel.

The purpose of this research is to develop a mathematical model which will aid the decision-makers of a moderately-sized NATO country to develop their future force structure composition. As the number of alternatives grows, and as the consequences become more important and more uncertain, the force structuring decision becomes increasingly difficult. The valuable lessons of past experience cannot be ignored. However, when one considers the high rotation rates of most countries' air forces, the rapid change in technology and the vast array of options available, even the most experienced leaders need some assistance. Hence, decision support tools are needed to aid senior-level decision processes. This research addresses a quantitative analytical support tool for senior decision-makers to use for future procurement decisions.

### 1.3. Problem Definition

Effective allocation of limited resources is increasingly critical for day-to-day operations for any air force. Weapons systems, depending on their mix of armament, can be more, or less, efficient in attacking a variety of targets. The role of the decision-maker is vital for selecting that correct mix. Decision-makers need tools to assist in finding the

"right" answers for future conflict situations. Such models may include many thousands of variables and constraints.

The purpose of this research is to provide quantitative analytical support to the senior decision-makers of a moderately-sized NATO country considering its future force structure composition. In this research, the basic decision variables are the number of sorties flown by each aircraft type against each target. The objective function is to destroy as many targets as possible based on total number of aircraft, munitions and targets respectively. To perform this objective weather, location, and attrition rates must be considered.

### 1.4. An Overview

The remainder of this thesis presents the research and results. Chapter 2 is a literature review of the key models used by the USAF during past 30 years. These include;

1. Heavy Attack,
2. Theater Attack Model (TAM),
3. Mixmaster,
4. Conventional Targeting Effectiveness Model (CTEM),
5. Combat Forces Assessment Model (CFAM).

Although there are some publications about the formulation of these models, well-detailed documented sources are limited (due to classification levels). Chapter 2 focuses on the developmental phase of these models. Each method is briefly described.

Appropriate parts of the each model are considered as a starting point for the construction of the new model.

Chapter 3 develops the suggested model for a moderately-sized NATO country. Chapter 4 presents the analysis of a hypothetical scenario solved by the proposed model and comments about the results. Chapter 5 concludes the research with an examination of the best alternatives and recommendations for future possible research areas

# II. LITERATURE REVIEW

## 2.1. Introduction

The USAF has proposed a variety of optimization models over the last several decades to determine its munitions stocks. Objective functions and constraints for these problems vary from model to model to satisfy the different needs of the subdivisions of the USAF. The USAF has developed all these models to determine the best inventory and best strategy to allocate their resources. This literature review focuses on the models: Heavy Attack, Theater Attack Model (TAM), Mixmaster, Conventional Targeting Effectiveness Model (CTEM), and Combat Forces Assessment Model (CFAM), previously developed.

## 2.2. Heavy Attack

Heavy Attack is the oldest of the models reviewed, having been in use since 1973. The model was originally formulated in the Office of the Secretary of Defense and was implemented by RAND (Clasen, Graves, and Lu, 1974). Heavy Attack is a program which uses an internal nonlinear optimizer to identify a set of sortie allocations that maximizes the military worth of target kills (Target Values) given forecasted weather states. This is done by assigning sorties, which use the best delivery tactics in each weather state with available weapon platform and munitions stocks. In 1988

approximately \$2 billion worth of weapons were purchased with guidance from Heavy Attack; additional expenditures of \$5.2 billion were planned for 1994-1999 (Brown, Coulter and Washburn, 1994:13). The optimization is done myopically for a single period. The objective in each period is to gain kills with as much target value as possible without regard to the effect on future periods.

Heavy Attack considers a series of allocation problems, each corresponding to one time period in a war that is projected to be several time periods long. If there are any surviving targets (undamaged) in any time period, those targets are still available in the next time period, along with additional targets and with ones that were killed in previous periods, but since repaired, possibly with different Target Values. Heavy Attack's myopic approach of representing time is analytically convenient, since it permits the analysis of a sequence of small problems rather than one large problem.

Heavy Attack determines the best weapon for each combination of aircraft, target, and weather state, and computes a composite effectiveness for an aircraft sortie against a target using an input weather distribution. It does not model aircraft attrition; available sorties are an input, and the model's allocation does not affect available sorties. It does not contain budget constraints. It has the single objective of maximizing Target Value Destroyed (TVD).

When it was first formulated, Heavy Attack was a nonlinear program with at most 10 sortie types, and 45 target types. Solving such moderate sized nonlinear problems was a challenge in the 1970s. However, computational power has improved considerably since then. In 1989, Washburn defined a new solution method, tailored to the Heavy Attack problem that solves this nonlinear objective function version with 13

sortie types and 61 target types in about two seconds on an 80386-class computer. (Brown, Coulter and Washburn, 1994:13-17).

Given hardware and software advances, computation time considerations have been relaxed to the point where reformulation can be considered. On the other hand, the long and successful life of Heavy Attack as a planning tool makes it difficult to consider any reformulation. As a result, most of the new implementations of the model focused on the computational efficiency and ease of use.

Note that the current system includes no budget constraint, even though it was designed as a budgetary tool. SELECTOR, a computer program designed for calculating kills per sortie is used to support calculations. The cost per sortie, given sortie effectiveness inputs, $E_{ij}$, utilizes cost inputs in determining the most cost-effective tactic, but weapon usage is not actually constrained by any budget. SELECTOR adopts only the most cost-effective tactic: literally, the tactic that maximizes the ratio of sortie cost to sortie effectiveness. Because of these conditions, Heavy Attack output can therefore be interpreted as the classic military *requirements* for weapons, with some implied budget level.

In 1989, Wirths developed several new formulations for the objective function (Brown, Coulter and Washburn, 1994:13-17). He stated that using a linear objective function is not as effective as had been thought and asserts that the myopic approach to optimization over time is possibly of more concern.

The degree of aggregation in the model, along with the use of advanced nonlinear programming techniques, makes Heavy Attack very small and very fast, with response times in seconds (Yost, 1996: 3).

**Objective Function of HEAVY ATTACK: Lord, 1982: 11**

***Indices:***

$i$ : aircraft type index $i = 1,2,3\ldots,I$

$j$ : target type index $j = 1,2,3,\ldots,T$

$v_j$ : subjectively-assessed value of a target of type $j$

$S_{ij}$ : number of sorties

$D_j$ : cumulative number of targets killed in prior time periods

$K_j(S_{ij})$: number of kills of target type $j$, a nonlinear function of $S_{ij}$.

$K_j$ is defined to be a function of the independent variables $S_{ij}$:

$$K_j(S_{ij}) = \frac{T_j}{C_j}(1 - \exp(-\frac{C_j}{T_j}(a_j + \sum_{i=1}^{I} P_{ij} * S_{ij}))) \text{ where,}$$

$T_j$ : number of type $j$ targets

$a_j$ : $\frac{T_j}{C_j}\log(1 - \frac{C_j}{T_j}D_j)$ a term added for mathematical convenience

$P_{ij}$ : expected number of type $j$ targets killed per type i aircraft sortie when no other targets of type $j$ have been previously killed and when conditions of kill conformability are perfect.

$C_j$ : target kill conformability parameter ($0 \le C_j \le 1$) controlling the extent to which the law of diminishing productivity. If conditions allow a pilot

confirm whether he hit the target or not with his first bomb, then $c_j$ should be zero. This is called shoot-look-shoot tactic. If he does not know the result of the first bomb then he drops all his weapons which is called dump-all-ordnance.

***Constraints:***

1. Sorties available

$$\sum_{j=1}^{J} S_{ij} = S_i \qquad i = 1, 2, 3, \ldots, I \text{ where } S_i \text{ is the number of sorties for aircraft type } i$$

2. Total Target

$$\ell_j \le K_j \le T_j \qquad j = 1, 2, 3, \ldots, J$$

where $\ell_j$ = lower bound on targets of type $j$ which must be killed.

3. Flight Composition

$$\delta(\sum_{j \in J_m} (1-\Theta_m)S_{i_m j} + \sum_{j \notin J_m} (-\Theta_m)S_{i_m j}) \le 0 \qquad m = 1,2,3,\ldots,M \qquad \text{where,}$$

$m$ flight composition constraint index ($m = 1,2,3,\ldots,M$)

$i_m$ aircraft type

$\delta_m$ +1, maximum and –1 for minimum

$J_m$ set of targets for which a maximum (minimum) flight composition is required.

$\Theta_m$ maximum (minimum) proportion of sorties flown by aircraft type $i_m$ against targets included in set $J_m$.

$K_j$ is computed assuming "a law of diminishing marginal productivity...*i.e.* the number of targets per sortie decreases for each successive sortie". The basic assumption behind this idea is the more targets that are killed, the more difficult it is for the pilot to discriminate among live and dead targets as the campaign continues (Lord, 1982: 12).

Parameter $c_j$, where *j* represents target type bridges the situation where command and control is impossible ($c_j = 1$) and where it is perfect ($c_j = 0$). This parameter is included in the model to represent the assumption that sorties can be coordinated so that targets that have already been killed will not be further attacked. If $c_j = 0$ then the objective function changes into a Linear Program (LP). However, the precise meaning of $c_j$, and how to set it, has not been defined. In 1985, Boger and Washburn applied some enhancements to the objective function where the parameter $c_j$ has a physical interpretation (Brown, Coulter and Washburn, 1994:13-17).

### 2.3. Theater Attack Model (TAM)

The Theater Attack Model (TAM) was developed by the Air Force Center for Studies and Analyses (AFCSA) in the mid-1980 as a replacement for Heavy Attack. To compensate for the gaps in Heavy Attack, Robert J. Might developed a model which measured the value of a particular weapon system or munitions in the context of the

entire conflict in a theater war. In his model Might suggested that key questions in attack planning include:

- How effective is an aircraft/munitions combination against each target type?
- How effective is the enemy at destroying the aircraft when it is employed with a given munitions against a specific target?
- How many times will an aircraft/munitions combination be able to engage a target of each type?
- How valuable is each target type, and how many targets of each type are there?
- How long is the conflict going to last? (Might, 1987: 63)

Might states that these critical issues cannot be examined solely through strict weapons effectiveness studies where a weapon system is matched against a few other weapon systems. One needs to consider the entire campaign. TAM, therefore, was conceived to consider a multi-period conflict, across multiple weather bands, over varying sortie distances while accounting for the effectiveness (the probability of kill) of each aircraft and munitions combination against each target type, in each different weather band. The available data was used in the following categories to provide examples to the Air Force Staff Board in 1985:

- The expected attrition (the probability of loss) of each aircraft against each target,
- The number of sorties (engagements) per day that an aircraft/munitions combination fly,

- Current aircraft and munitions inventory,
- The number of targets by type and the value of each type,
- The procurement costs of new aircraft, and munitions (Might, 1987:59).

TAM is a highly detailed model which allocates sorties by aircraft, weapon, target type, target distance, weather state and time period. In addition, TAM offers an array of objective functions (*i.e.* Maximizing TVD), budget constraints and attrition constraints. Unlike Heavy Attack, TAM's objective functions are all linear. Battle Damage Assessment (BDA) is not directly modeled in TAM, but instead available sorties are affected by attrition. TAM assumes the weather is known with certainty. The model uses the weather distribution to constrain the proportion of time each sortie type can be used.

TAM optimizes globally across time, but this feature and the other dimensions in the model make the resulting optimizations very large. At one point in time, TAM was one of the largest LPs used by the Pentagon, having 3500 constraints and 250,000 variables (Jackson, 1989:1). The size of this full version of TAM was not convenient for use by small agencies or sub-commands. For their convenience, smaller versions of TAM were developed. These smaller models are easier to manipulate, yet provide strong insight despite their small size. TAM solution times for typical scenarios and current hardware take about an hour (Yost, 1996: pp. 3).

Unless otherwise noted, the following description of TAM has been taken from Jackson (Jackson, 1989, Appendix B) as an overview of the model.

***Parameters:***

| | |
|---|---|
| $a$ | aircraft type |
| $m$ | munition type |
| $t$ | targets |
| $d$ | distance bands |
| $t$ | time bands |
| $w$ | weather bands |
| $s$ | spares for each aircraft |

**Decision Variables:**

| | |
|---|---|
| $X_{amkd}$ | sorties with aircraft $a$, carrying munitions $m$, to target $k$, in distance band $d$, during time band $t$, in weather $w$. |
| *NAC* | new aircraft purchased |
| *NMN* | new munition purchased |
| *NSPR* | new spares purchased |
| *YLD* | yield per sortie, calculated based on the expected mission effectiveness and attrition. |
| *TGTVAL* | target value, assigned by target type, time period, and distance band. *TGTVAL* represents the value of one target type $k$ at distance $d$ and time $t$ . |
| *TS* | maximum number of sorties that could be flown by type aircraft $a$, during time period $t$ against target $k$ using munitions $m$ in weather band $w$ to a penetration depth $d$ |

*STARTAC* the number of starting aircraft of type $a$

*FILL* the number of type $a$ aircraft arriving during time period $t$

$e_a, e_m, e_s$ small multipliers, typically in the 0.001 to 0.00001 range, used for forcing the model to use existing aircraft and munitions prior purchasing a new like item.

$a_{amkdtw}$ expected attrition for a single mission using aircraft $a$, carrying munitions $m$, against target $k$, in distance band $d$, during period $t$, and weather state $w$.

*PRCNT* percent of time that type $w$ weather is expected to occur.

*LOAD* number of munitions $m$ carried on aircraft type $a$ to distance band $d$.

*STARTMN* starting inventory of munition $m$.

*STARTGT* initial target set.

$b_{kzm}$ the regeneration rate for each target type. The $b_{kzm}$ is calculated based on intelligence estimates of the enemy's repair capacity for that target type and the number days in the time period. $b_{kzm} = 0.5$ means that half the one targets destroyed during time period one will regenerate and be operational in time period two.

*NSORT* fixed number of sorties to be flown by aircraft $a$ during time period $m$.

*AGSORT* input number of sorties flown by aircraft type $a$ against ground threat targets during time period $t$.

*AASORT* input number of sorties flown by aircraft type $a$ against airborne threat targets during time period $t$.

*INSPR* inventory of type $s$ spares resource available for use on aircraft type $a$ during time period $t$.

*NSPR* new type $s$ spares resource produced during time period $t$ for use on aircraft type $a$.

*MKILL* minimum number of targets of type $k$ which must be killed during time period $t$.

*KILL* number of type $k$ targets destroyed during time period $t$ in distance $d$.

*MINSORT* required percentage of sorties which must be flown during time period $t$. This percentage applies to the sum of all aircraft sorties flown during time period $t$.

*MAXATT* maximum percentage of available type $a$ aircraft which are allowed to be attrited during the war.

*SPRCOST* cost to procure spares resource $s$ for each additional sortie flown by aircraft type $a$.

*ACCOST* cost to procure an aircraft of type $a$.

*MNCOST* cost to procure a munition of type $m$.

## Objective Function

Maximize TVD (Target Value Destroyed). Total value of all targets destroyed as a result of the optimization.

$$MaxZ = \sum_a \sum_m \sum_k \sum_d \sum_t \sum_w X_{amkdtw} YLD_{amkdtw} TGTVAL_{kdt} -$$

$$\left[\left(e_a \sum_a \sum_t NAC_{at}\right) + \left(e_m \sum_m NMN\right) + \left(e_s \sum_a \sum_t \sum_s NSPR\right)\right]$$

***Constraints:***

1. Total aircraft constraint per period.

$$\sum_m \sum_k \sum_d \sum_w X_{amkdtw} / TS_{amkdtw} \leq STARTAC_a + \sum_t FILL_{at} + \sum_{t-1} NAC -$$

$$\sum_{t-1} \left( \sum_m \sum_k \sum_d \sum_w X_{amkdtw} a_{amkdtw} \right) \qquad \text{for each } a, t$$

For each aircraft type, this constraint ensures that the total aircraft used during each time period equals the sum of starting aircraft ($STARTAC_a$) plus filler aircraft ($FIIL_{at}$) in that period plus new aircraft ($NAC$) bought in previous time period minus the aircraft lost in previous time period ($X_{amkdtw} a_{amkdtw}$).

If the total number of sorties flown by aircraft type $a$ is divided by the total number of sorties that aircraft type $a$ *can* produce (considering sortie rates and

attrition rates for each aircraft type), the result in the total number of aircraft necessary to fly that number of sorties.

2. Optional constraint to force sorties to fly across all weather bands.

$$\sum_m \sum_k \sum_d \frac{X_{amkdtw}}{TS_{amkdtw}} \leq PRCNT_w \left[ STARTAC_a + \sum_t FILL_{at} + \sum_t NAC_{at} - \sum_{t-1} \left( X_{amkdtw} a_{amkdtw} \right) \right]$$

for each $a, t, w$

If the total number of aircraft in that period is multiplied with the percent of the time that type $w$ weather is expected to occur ($PRCNT_w$) the aircraft usage across the weather band is consistent with the expected weather distribution.

3. Total munitions used across the war must be less than starting inventory plus those newly purchased.

$$\sum_a \sum_k \sum_d \sum_w X_{amkdtw} LOAD_{amd} \leq STARTMN_m + NMN_m \text{ for each } m$$

The number of each munitions type used in each sortie ($LOAD_{amd}$) with the number of sorties, which are flown with the same type of munitions ($X_{amkdtw}$), the total number of munitions necessary for the entire campaign can be calculated.

4. Total targets constrained per distance and time band.

$$\sum_a \sum_m \sum_w X_{amkdtw} YLD_{amkdtw} \leq STARTGT_{kd1} \quad \text{for each } k, d, t=1$$

$$\sum_a \sum_m \sum_w X_{amkdtw} YLD_{amkdtw} \leq STARTGT_{kd(t=1)} - KILL_{kd(t=1)} + \sum_{z=1}^{t-1} b_{kzt} KILL_{kdz}$$

$$\text{for each } k, d, t$$

The first constraint ensures that the number of type $k$ targets destroyed in distance band $d$ during the first time period must equal the number of sorties flown against those targets times, the effectiveness of the sortie (probability of kill of a sortie against a target type $k$). The second constraint ensures that the number of targets available for attack during time periods two and later equal to the number of targets surviving the previous time period, plus those that regenerate during this time period.

5. Budget constraint.

$$\sum_a \sum_t (NAC_{im} ACCOST_a) + \sum_m (NMN_m MNCOST_m) +$$

$$\sum_a \sum_t \sum_s (NSPR_{ats} SPRCOST) \leq BUDGET$$

The budget constraint limits procurement of additional aircraft, spares, and munitions to a specified budget level by summing all the individual costs which

are equal to number aircraft/munitions/spare parts, times the cost of each of them, respectively.

6. Maximum attrition rates per aircraft.

$$\sum_{a}\sum_{t}\sum_{d}\sum_{w}(X_{amkdtw}a_{amkdtw}) \leq MAXATT_a(STARTAC_a + \sum_{t} FILL_{at} + \sum_{t} NAC_{at})$$

for each $a$

This constraint limits the attrition for each aircraft type to a specified percent of the force. The left side of the equation gives the total attrition for each aircraft type. This value must be smaller than what is defined before according to some planning factors (political or economical reasons).

It should be noted that in World War II, the Royal Air Force (RAF) Bomber Command suffered overall attrition of 40 aircraft on their night raids over Europe during 1942 and 1943. Attrition rates of some of these missions were as high as 5% of the attacking bomber aircraft. On the other hand, heavily escorted day raids by the RAF during the later half of 1942 suffered an overall loss rate of over 10%. Since the loss rate on the escorted daylight raids were so high, Bomber Command decided to conduct most of their subsequent operations at night. It is important to note that a loss rate of 5% results in a probability of an aircraft surviving 25 sorties (the typical tour of duty for aircrews in World War II) of $(1-0.05)^{25}$, or about 28%. In other words, the probability of survival of an aircraft after the 25 sorties was 28% (Ball, 1985:119).

7. Minimum sorties per time period that must be flown.

$$\sum_{a}(EAC_{at} + NAC_{at}) \geq MINSORT_{t}\left[STARTAC_{a} + \sum_{a}\sum_{t} FILL_{at} - \sum_{a}\sum_{t-1}(X_{amkdtw}a_{amkdtw})\right]$$

for each $t$

This constraint forces the model to fly the minimum percentage of available sorties by the time period. The left side of the equation is the total number of aircraft, which is the sum of existing aircraft and new aircraft bought at that period.

8. Minimum targets killed per time period.

$$\sum_{a} KILL_{kdt} \geq MKILL_{kt} \quad \text{for each } k,t$$

The minimum targets killed per time period constraint forces the model to kill a user-specified number of type $k$ targets during each time period. This means that the number of type $k$ targets killed during time period $t$, in distance band $d$, must be greater than or equal to the minimum number of targets of type $k$ which must be killed at the same time period $t$.

9. Minimum aircraft sorties per weather band.

$$\sum_{m}\sum_{t}\sum_{d} X_{amkdtw} = PRCNT_{w}(NSORT_{at}) \quad \text{for each } a,t,w$$

This constraint forces the model to distribute the fixed sorties across weather bands. Total number of sorties flown by each aircraft must be equal to the fixed number of sorties to be flown by aircraft type $a$ during time period $t$, times the percentage of the time that type $w$ weather is expected to occur.

10. Target Value Destroyed

$$TVD = \sum_a \sum_m \sum_k \sum_d \sum_t \sum_w X_{amkdtw} YLD_{amkdtw} TGTVAL_{klm}$$

Total TVD is equal to the over all sum of the sortie times the effect of that sortie on the target (probability of kill of that sortie) times a subjectively specified value of that particular target. Fixes a specific number of air-to-ground sorties.

$$\sum_d \sum_w X_{amkdtw} = AGSORT_{at} \quad \text{for each } a, t, m, k$$

This constraint forces the model to fly a specified number of sorties against a generic ground based threat oriented target. The sorties are specified by aircraft type and time period. $AGSORT_{at}$ is the input number of sorties flown by aircraft type $a$ against ground threat targets during time $t$.

11. Fixes a specific number of air-to-air sorties.

$$\sum_d \sum_w X_{amkdtw} = AASORT_{at} \quad \text{for each } a, t, m, k$$

This constraint forces the model to fly a specified number of sorties against a generic airborne threat-oriented target. The sorties are specified by aircraft type and time period. $AASORT_{at}$ is the input number of sorties flown by aircraft type $a$ against airborne threat targets during time period $t$.

12. Limits the sorties flown during a time period to those supported by spares.

$$\sum_m \sum_k \sum_d \sum_w X_{amkdtw} \leq \sum_t (INSPR_{ats} + NSPR_{ats}) - \sum_m \sum_k \sum_d \sum_{t-1} \sum_w X_{amkdtw}$$

for each $a,t,s$

The right hand side of the equation calculates the inventory of type $p$ spares resource available for use on aircraft type $a$ during time period $t$. Inventory unused during time period $t$ rolls over into $t+1$. This inventory represents the spares supported sorties available at no additional cost.

13. Upper and lower bounds on procurement of aircraft, munitions, and spares.

$$LMN_m \leq NMN_m \leq UMN_m \qquad \text{for each } m$$

This constraint is for the upper and lower limits of the number of additional type $m$ munitions purchased. This constraint is used to keep weapon procurement below production line maximum capacities, and procure no more than some maximum number of munitions type $m$.

$$LAC_a \leq NAC_a \leq UAC_a \qquad \text{for each } m$$

$UAC_a$ is the upper bound on aircraft type $a$ procurement. This constraint prevents buying more aircraft than can be produced. At the same time, this constraint forces the model to buy at least some minimum number of munition $m$ to keep the production lines open.

$$LSPR_{as} \le NSPR_{az} \le USPR_{as} \qquad \text{for each } a, s$$

This constraint limits the procurement of additional spares resources based on production constraints or availability. Lower bound forces procurement of at least some minimum number of spare resources. Overall TAM provides a range of modeling options.

## 2.4. Mixmaster

Mixmaster is a collective name which refers to both an optimization model and a heuristic method developed at the USAF's HQ Air Combat Command as a response to dissatisfaction with Heavy Attack in 1990. The Joint Studies Group (JSG) developed the Mixmaster model to aid decision-makers in determining weapon systems requirements (Yost, 1996:54).

The Mixmaster linear program is a time-myopic version of TAM with only the TVD objective function. The Mixmaster heuristic is a greedy sortie allocation scheme that uses target values to determine the proportion of sorties dedicated to each target type. The basic decision variable of the model is the *Number of Sorties Flown.* Since the first construction of Mixmaster did not include any cost figures, it could not answer questions

about cost while optimizing the *Target Value Destroyed.* Mixmaster has six parameters representing aircraft type, weapon type, target type, distance band, time, and weather condition. Since Mixmaster includes fewer parameters than TAM, it runs very quickly even on a desktop computer (Dengur, 1992:1-4).

Capt Skip Langbehn of the ACC/JSG proposed a different approach for TAM. In its complete formulation, TAM updates all the constraints during the entire campaign. For instance, if there are 100 targets for the first day of the conflict, the TAM formulation, at first, subtracts the number of targets destroyed from the total target set of the first day targets and then adds the number of targets which are reconstructed before the second period begins.

TAM follows the same logic for the total number of aircraft attrited. If there are 200 aircraft available for the first day of the conflict, TAM's formulation updates the total number of available aircraft for the second day by considering the number of aircraft lost on the first day. This complete formulation of TAM includes nearly 5000 rows and 8.75 million columns when dealing with the real global war situation (Jackson, 1989:1).

In their respective research Langbehn and Dengur noticed the sheer size of TAM and developed a new approach by eliminating the implicit updating constraints to reduce the number of constraints, and therefore the CPU-time. Besides their contribution to reducing the CPU-time of Mixmaster, they modified the formulation to give answers to the questions about the cost of the campaign and to make the model more operationally sound (Dengur, 1992:2-3).

As mentioned, the objective function of Mixmaster maximizes the Target Value Destroyed. Previous attempts to modify the objective function with the aircraft cost so as

to maximize *Target Value Destroyed per Aircraft Dollar* ended up with inconsistent results when compared with the campaign objectives. This happened because, as long as the attrition rates of the two different aircraft are similar, the model always chooses the cheaper aircraft since the difference in probability of kill ($P_k$) values of these two aircraft are not as significant as their costs (Dengur, 1992:1-5).

In his suggested model, Dengur employed three basic constraints associated with the *Total Available Aircraft, the Total Available Munitions, and the Total Available Targets.* They assumed that new munitions were already in the inventory, and if there was a positive difference between the number of weapon systems used and the existing inventory at the end of a run, that meant a new weapon systems needed to be procured (Dengur, 1992:2-4).

Although the actual duration of the conflict is determined by the campaign objectives, Dengur employed the first time period of the conflict in his research without considering whether the campaign was over or not. His suggestion for the procurement decisions only considers the first time period. If the campaign lasts longer than the first period, and usually it does, then successive runs are performed with the updated resource values to determine the new requirements.

Without defining an additional variable, Mixmaster can determine which weapons should be procured by relaxing the aircraft and munitions constraints right hand sides (RHS) as if they are unlimited. If there is a positive difference between the relaxed RHS and the current inventory, it means that new procurement of that weapon is necessary for the success of that mission.

On the other hand, Mixmaster's operational reliability is questioned since it possible to assign a close support type aircraft (e.g. A-10 aircraft) to an enemy air base target deep in enemy territory (Dengur,1992:1-5). Langbehn and Dengur suggested defining an additional constraint, which reflects the decision-maker's choices about how the operation will be executed to the model. This is defined as:

$$\sum_{m}\sum_{t}\sum_{w} X_{amkdtw} \leq ATD_{akd} TSORTAC_{a} \qquad \text{for each } a, k, d$$

where $ATD_{akd}$ represents the predetermined sortie percentage of aircraft type $a$ against target $k$ in distance band $d$ and $TSORTAC_a$ is the total number of sorties that an aircraft type can fly. The total sorties that an aircraft can fly is computed by

$$TSORTAC_{a} = \sum_{m}\sum_{k}\sum_{d}\sum_{t}\sum_{w} TS_{amkdtw} \qquad \text{for each } a$$

Depending upon on the characteristics of the aircraft type, the upper limit for that aircraft type, which will be assigned in a specific part of the enemy territory, is determined for the model by the planners. In the planning phase of the air campaign, the number of the aircraft allocated to a specific type of target is limited (e.g. 85% of the total A-10 sorties will be assigned to enemy runways in the second distance band of the enemy territory) so that the upper limit of the A-10 missions against the runways in the second distance band can be formulated as:

$$ATD_{A-10,RUNWAYS,DIST-1}TSORTAC_{A-10} = 0.85TSORTAC_{A-10}$$

The following description of Mixmaster is taken from Dengur (Dengur, 1992:3-3) where otherwise noted. Mixmaster is a fairly aggregated version of TAM. The model uses three basic constraints: aircraft availability, weapon availability, and the target availability constraints. The basic decision variable $X_{amkdtw}$ represents *Number of Sorties Flown* by each combination of aircraft $a$ loaded with weapon $m$ against target $k$ in distance band $d$ at time $t$ and subject to weather condition $w$.

***Decision Variables:***

| | |
|---|---|
| *TGTVAL* | represents the target value related to the distance band |
| *EXKILL* | expected number of targets destroyed. |
| $TS_{amkdtw}$ | total sorties that can be flown by aircraft $a$ loaded with munition $m$ against target $k$ in distance band $d$ at time $t$ and in weather condition $w$, calculated as: |

$$TS_{amkdtw} = \frac{1-(1-ATTRIT_{amkdtw})^{SR_a NDAYS_t}}{ATTRIT_{amkdtw}}$$

Let $SR_a = 2$, $NDAYS_t = 10$ and attrition rate ( $ATTRIT_{amkdtw}$ ) $= 0.01$. Attrition means a planner can expect to lose some percentage of total aircraft launched for a sortie.

If 200 aircraft are launched, a planner expects to lose 2 sorties, according to this formulation 2 aircraft. If aircraft comes back that sortie is considered as successful.

$$1 - ATTRIT_{amkdtw}$$

is a success of a single sortie. (1-0.01=0.99).

$$(1 - ATTRIT_{amkdtw})^{SR_a NDAYS_t}$$

is a percentage for a single aircraft type $a$ of producing unsuccessful sorties during 20 days.($0.99^{2*10} \cong 0.8179$).

$$1-(1 - ATTRIT_{amkdtw})^{SR_a NDAYS_t}$$

is a percentage for a single aircraft type $a$ of producing unsuccessful sorties in 20 days.($1-0.8179 \cong 0.182$).

$$\frac{1-(1 - ATTRIT_{amkdtw})^{SR_a NDAYS_t}}{ATTRIT_{amkdtw}}$$

is the total number of sorties that a single aircraft type $a$ *can* produce during 20 single days. $0.182 \div 0.01 \cong 18.2$ sorties can be produced by a aircraft type $a$.

$SR_a$ : sortie rate for an aircraft

$NDAYS_t$ : duration of the mission

$ATTRIT_{amkdtw}$ : attrition to whichever combination of aircraft $a$ loaded with munitions

$m$ against target $k$ in distance band $d$ at time $t$ and in weather condition $w$ is expected.

$TOAC_a$ : total available aircraft at time $t$

$TOWPN_m$ : total available weapons

$WPNLD_{am}$ : number of weapons type $m$ that an aircraft can carry

$TOTGT_{kd}$ : total number of targets in each distance band

**Objective Function**

$$MaxTVD = \sum_a \sum_m \sum_k \sum_d \sum_t \sum_w X_{amkdtw} EXKILL_{amkdtw} TGTVAL_{kd}$$

***Constraints:***

1. Total Number of Aircraft

$$\sum_m \sum_k \sum_d \sum_t \sum_w \left[ X_{amkdtw} \middle/ TS_{amkdtw} \right] \leq TOAC_a \qquad \text{for each } a$$

The total number of each aircraft type required can be limited by dividing the total number of sorties flown ($X_{amkdtw}$) with the total number of sorties that can be produced by a single aircraft type ($TS_{amkdtw}$) which takes care of the attrition and sortie rate for that particular aircraft type.

2. Total Number of Weapons

$$\sum_a \sum_k \sum_d \sum_t \sum_w X_{amkdtw} WPNLD_{am} \leq TOWPN_m \qquad \text{for each } m$$

If the number of weapons carried by an aircraft type $a$ in each sortie is multiplied by the number of sorties flown with that munition type, the total number of munitions necessary can be calculated.

3. Total Number of Targets

$$\sum_a \sum_m \sum_t \sum_w X_{amkdtw} EXKILL_{amkdtw} \leq TOTGT_{kd} \qquad \text{for each } k \text{ and } d$$

If the total number of sorties flown ($X_{amkdtw}$) against each target type and to the each distance band is multiplied with the Probability of Kill ($P_K$) value of that particular sortie ($EXKILL_{amkdtw}$) separately, the total number of targets according to their location and types can be calculated.

**Suggested Formulation of MIXMASTER: for Simple Cost Employment**

**Langbehn and Dengur, 1992: D-7**

$$MaxTVD/Dollar = \sum_{a}\sum_{m}\sum_{k}\sum_{d}\sum_{t}\sum_{w}\frac{X_{amkdtw}EXKILL_{amkdtw}TGTVAL_{kd}}{MISCOST_{amkdtw}}$$

If the Total Target Value Destroyed is divided by the mission cost $MISCOST_{amkdtw}$, *The Target Value Destroyed per Dollar Spent* can be calculated where the mission cost is the total cost of losing an aircraft, plus cost of munitions used, plus fixed sortie cost.

$$MISCOST_{amkdtw} = ACCOST_{a}ATTRIT_{amkdtw} + COSTM_{m}WPNLD_{am} + SCOST_{a}$$

$ACCOST_a$ cost of aircraft $a$.

$ATTRIT_{amkdtw}$ attrition to whichever combination of aircraft $a$ loaded with munition $m$ against target $k$ in distance band $d$ at time $t$ and in weather condition $w$ is expected.

$COST_m$ cost of weapon $m$.

$WPNLD_{am}$ number of weapons of type $m$ that an aircraft can carry

$SCOST_a$ constant sortie cost for aircraft type $a$.

Mission cost is equal to the multiplication of the cost of an attrited aircraft ($ACCOST_a$) with the attrition rate ($ATTRIT_{amkdtw}$), plus the multiplication of the cost of a weapon ($COST_m$) with the number of weapons launched during that sortie $WPNLD_{am}$ plus sortie cost $SCOST_a$.

***Constraints:***

1. Total Number of Aircraft

$$\sum_m \sum_k \sum_d \sum_t \sum_w \left[ X_{amkdtw} \big/ TS_{amkdtw} \right] \le TOAC_a \quad \text{for each } a$$

The total number of each aircraft type required can be limited, by dividing the total number of sorties flown ($X_{amkdtw}$) with the total number of sorties that can be produced by a single aircraft type ($TS_{amkdtw}$) which takes care of the attrition and sortie rate for that particular aircraft type.

2. Total Number of Weapons

$$\sum_a \sum_k \sum_d \sum_t \sum_w X_{amkdtw} WPNLD_{am} \le TOWPN_m \quad \text{for each } m$$

If the number of weapons carried by an aircraft type $a$ in each sortie is multiplied, by the number of sorties flown with that munitions type, the total number of munitions necessary is calculated.

3. Total Number of Targets

$$\sum_{a}\sum_{m}\sum_{t}\sum_{w} X_{amkdtw} EXKILL_{amkdtw} \leq TOTGT_{kd} \qquad \text{for each } k \text{ and } d$$

If the total number of sorties flown ($X_{amkdtw}$) against each target type to each distance band is multiplied with Probability of Kill ($P_K$) value of that particular sortie ($EXKILL_{amkdtw}$) separately, the total number of targets according to their location and types is calculated.

4. Limiting the Sortie Amounts

$$\sum_{m}\sum_{t}\sum_{w} X_{amkdtw} \leq ATD_{akd} TSORTAC_{a} \qquad \text{for each } a,\ k,\ d$$

This constraint leads the model's allocation process by limiting the sortie numbers that are to be flown by each aircraft against a particular distance band. $ATD_{akd}$ represents the predetermined sortie percentage of aircraft type $a$ against target $k$ in distance band $d$ and $TSORTAC_a$ is the total number of sorties that an aircraft type can fly. The total sorties that an aircraft can fly is computed by

$$TSORTAC_{a} = \sum_{m}\sum_{k}\sum_{d}\sum_{t}\sum_{w} TS_{amkdtw} \qquad \text{for each } a$$

## 2.5. Conventional Targeting Effectiveness Model (CTEM)

The Conventional Targeting Effectiveness Model (CTEM) was developed in 1990 for analysis of current operations. CTEM is a derivative of the Arsenal Exchange Model (AEM), which has long been used for force structure analysis for nuclear weapons. CTEM allows the user to modify the objective function and constraints according to campaign objectives (Yost, 1996: 54).

CTEM takes as its input a set of tasks, where each task is a set of targets and desired level of damage to those targets, aircraft and weapon specifications, and information about air bases, sortie rates, and attrition rates. The final output assigns aircraft and weapons to targets in an attempt to meet the specified objectives by the decision-makers (Brown University, White Paper).

Typically, CTEM is used as a preemptive goal program where targets are grouped into target classes that must be attacked in a certain priority order; CTEM users normally do not use target values. In addition, CTEM has the capability to allocate suppression of enemy air defense (SEAD), and ECM/jamming sorties. CTEM does have some BDA modeling capability. It can assign multiple costs to aircraft and weapons, and either constrain or optimize any combination of these costs. The current version of CTEM operates in two phases. The output of the first phase is a sourcing that identifies aircraft, weapon, and target types, and makes a rough assignment of weapons to aircraft and aircraft to targets. This part of the solution is adequate for most strategic planning purposes and in particular for in-theatre inventory planning and asset and crew assignment (Haas, 1998:35).

The second phase takes the sourcing and produces a complete package that involves grouping aircraft into flight groups, planning approaches (delivery profiles), putting together jamming, communications, and other support craft (e.g., to take out SAM sites), and planning in-flight refueling and flight paths. Path deconfliction is generally not part of packaging. This packaging is necessary for a human expert to verify that a sourcing is reasonable (Brown University, White Paper).

CTEM is a mathematical tool which optimizes based only on the mathematical goals specified by the user. Although a highly capable model, CTEM's aggregation and assumptions limit the fidelity of the model. Different uses of the model require different levels of fidelity. The problems that CTEM is designed to solve involve various sources of uncertainty.

In the case of air campaign planning, the primary sources include weather, attrition rate (e.g., loss of aircraft due to mechanical failure, pilot error, and enemy action), terrain and its effect on weapon delivery, air and ground based defense, availability of aircraft, crews and weapons, weapon effectiveness against a given target, delivery profiles, aircraft condition, target characteristics, and performance of crews and aircraft over the course of a campaign.

The primary source of uncertainty is due to damage assessment how much damage a particular weapon can be expected to inflict on a particular target under a variety of circumstances. These estimates are obtained from SABSEL, which combines the SABER and SELECTOR models into a single computer model which generates weapon effectiveness and supplies aircraft attrition data.

The SABER model estimates the effectiveness of many combinations of aircraft, weapons, and delivery profiles against many targets. The model calculates the probability of target kill for each combination using the accepted documented JMEM OPEN-END methodology. The computations are based on data in the JMEM/AS Basic Manual, Target Vulnerability Manual, Weapons Characteristics Manual, and the Delivery Accuracy Manual. In conjunction with the previously stated data, the SABER model also outputs the aircraft attrition data and cost data, all of which will be input into the SELECTOR model which calculates kills per sortie and cost per kill.

A query to the SABSEL database allows CTEM to estimate the probability of inflicting a specified level of damage on a given target type for a given attack strategy. Targets are grouped into 198 target types. Attack strategies are characterized in terms of 150 weapon types, 6 weather types, 30 aircraft types, a number of aircraft delivery profiles, and assorted weapon accessories including fuses, fins and electronics. These so-called P/D (probability for specified damage level) estimates were obtained by weapons experts examining damage to targets in combat as well as controlled experiments specifically designed to test the effectiveness of weapons (Brown University, White Paper).

However, other criteria such as desired target damage at a specific time or fuel or range may be appropriate. For smaller conflicts, it may be better to optimize for tactics or doctrine. CTEM solution times range from one to three hours, depending on the scenario being analyzed (Haas, 1998:34-43).

## 2.6. Combat Forces Assessment Model (CFAM)

The differences among the existing models led to serious disagreements over weapons requirements. In 1995, the USAF Office of Aerospace Studies (OAS) was given the task of combining and extending the three existing models Heavy Attack, TAM and Mixmaster (Yost, 1996:ii). Subsequently, OAS has produced two variants of the same formulations.

The first set of models, called Quick Strike, operates as a sequence of optimizations. Quick Strike optimizes sortie allocations for a single period, and passes the output from that period to the next period's optimization. This time-myopic approach keeps the model small and fast, but complicates global analyses and forces the user, rather than the model, to explicitly define how resources can be used across time. The other variant, called Time Strike, globally optimizes allocations across time. These two names survive as submodels under the new name for the entire system, the Combat Forces Assessment Model (CFAM) (Yost, 1996: 2).

Time Strike is a family of optimizations with a common objective. In each instance, Time Strike decides how best to allocate aircraft sorties and weapons to targets in a particular scenario, subject to various budget and availability constraints. However, Time Strike differs in eight basic areas:

- New objective functions that are oriented towards campaign objectives have been added,
- Sortie and target kill accounting have been changed,
- Time periods are treated explicitly,

- Battle Damage Assessment (BDA) and target regeneration have been revised,
- Weather effects have been reformulated,
- Operationally oriented limitations such as minimum altitudes for weapons deliveries have been added,
- Budget constraints have been revised and extended , and
- The ability to model simultaneous campaigns in two theaters has been included.

Although CFAM is a consolidation of former models, many new capabilities have been added that were not available in the existing models. CFAM is not restricted to a single formulation, but offers user-selectable objective functions and constraints to allow the analyst to tailor the model according to his or her own objectives. An analyst is free to select any one of the objective functions among the existing five objectives functions, three of which are retained from the existing models to give the users a sense of backward compatibility (Yost, 1996: 5).

Maximizing TVD is included in CFAM. In addition, CFAM includes two TAM objectives that do not use target values. The first minimizes aircraft attrition subject to a set of target destruction goals, while the second objective minimizes the cost of buying new aircraft and weapons subject to target destruction goals (Yost, 1996: 2).

## Formulation of CFAM

The following parameters are used to denote valid *n*-tuples (correspondences) of the index arguments. For example, *cc(k,c)* denotes the set of all admissible target-target

class combinations. Target classes in Time Strike are the major differences of the model from the existing models. The basic idea is to destroy related targets rather than individual targets by allowing the user to define a set of target types and set a time or phase-dependent goal for their destruction.

***Indices***:

| | |
|---|---|
| $i$ | aircraft |
| $j$ | weapon |
| $k$ | target |
| $l$ | loadout |
| $p$ | delivery profile |
| $w$ | weather state |
| $d$ | distance band |
| $c$ | target class |
| $f$ | weapon component family |
| $g$ | weapons qualification family |
| $b$ | budget |
| $cc(k,c)$ | target-target class correspondence |
| $fc(j,f)$ | weapon component family correspondence |
| $qc(j,q)$ | weapon-qualification family correspondence |
| $r(i,j,l,d)$ | aircraft-weapon-loadout-distance band correspondence |
| $wc(i,j,p,w)$ | aircraft-weapon-profile-weather state correspondence |

A target can be included in more than one-target class and each class may have its own time or phase-dependent goal. User-defined penalties determine the importance of achieving each particular goal. For instance, a sector ops center is included in two different target classes. If a planner uses phase-goal objective function then the planner should specify the proportion of targets in each class that need to be killed to end the phase. If the planner uses the other objectives, the planner should set these proportions by time period (Yost, 1996, pp. 6).

## Formulation

| | |
|---|---|
| $ACCOST_{ib}$ | budget $b$ resource consumed per aircraft $i$. |
| $ACMAXBUY_{ib}$ | maximum number of aircraft $i$ available for purchased in budget $b$ |
| $ATTR_{ijkp}$ | expected losses per sortie for combination $i, j, k, p$ |
| $ATTRWGT$ | objective function weight for attrition |
| $BDAREG_k$ | expected number of targets $k$ dead or in repair at the end of the time perod; adjusts for BDA errors and target regeneration |
| $BDGLIMIT_b$ | resource limit for budget $b$ |
| $BUYWGT_b$ | objective function weight for spending in budget $b$ |
| $CUMARRIVE_j$ | number of weapons $j$ scheduled to arrive this period |
| $EKS_{ijk}$ | expected kills per sortie for aircraft i, weapon $j$, target $k$, loadout $l$ |
| $FAMLIM_f$ | maximum number of common components available for weapon family $f$ |

| | |
|---|---|
| $GOAL_c$ | proportion of targets in target class $c$ to be killed to achieve the current goal |
| $HISTFORECAST_w$ | cumulative proportion of forecasts for weather states $1$ through $w$ |
| $INVENT_j$ | inventory of weapon $j$ on-hand |
| $LOAD_l$ | number of weapons carried per sortie for loadout $l$ |
| $MAXLOSS_i$ | maximum losses of aircraft $i$ allowed |
| $MUNWGT$ | objective function weight for munitions use |
| $NABORT_{ijp}$ | proportion of sorties by aircraft $i$ flying profile $p$ with weapon $j$ not aborted in-flight |
| $NDAYS$ | number of days in the time period |
| $PPEN_c$ | objective function penalty for not meeting the time-scripted goal for target class $c$ |
| $PROPORTION_{iq}$ | proportion of aircrews manning aircraft $i$ qualified to drop weapons in qualification class $q$ |
| $SORTWGT$ | objective function weight for sorties |
| $SR_i$ | sorties per day for aircraft $i$ |
| $TIMEAC_i$ | number of aircraft $i$ scheduled to arrive |
| $TOTTGTS_{kd}$ | total number of type $k$ targets |
| $TSORT_{ijkp}$ | expected number of sorties per aircraft for combination $i, j, k, p$ considering attrition |
| $WPNCOSTS_{jb}$ | resources consumed per weapon $j$ available in budget $b$ |
| $WPNMAXBUY_{jb}$ | maximum number of weapon $j$ available in budget $b$ |

***Variables:***

| | |
|---|---|
| $z$ | time-scripted goal objective value |
| $x_{ijklp}$ | sorties assigned |
| $pdiff_{kc}$ | proportion of kills below goal $c$ for target $k$ |
| $wpnbt_{jb}$ | weapons of type $j$ bought in budget $b$ |
| $acbt_{ib}$ | aircraft of type $i$ bought in budget $b$ |
| $onhanduse_j$ | existing inventory of weapon $j$ used |

## Objective Function

Since experience with Time Strike showed that objective functions have multiple optimal solutions, penalty terms are used to break ties on attrition, sorties, munitions expenditures, and weapons and aircraft purchases (Yost, 1996:23). These weights can be positive or negative. For example, a user may want to give a negative weight to *SORTWT* to influence the model to fly as many sorties as possible. These are:

1. $$at = ATTRWGT \sum_{ijklp} ATTR_{ijklp} x_{ijklp}$$

This equation helps the planner to include importance of attrition effect by multiplying the overall attrition ( $\sum_{ijklp} ATTR_{ijklp} x_{ijklp}$ ) with its objective function weight ( $ATTRWGT$ ).

2. $$so = SORTWGT\sum_{ijklp} x_{ijklp}$$

This equation covers the importance of total sorties assigned for the planner.

3. $$mu = MUNWGT\sum_{ijklp} LOAD_i \left[ ATTR_{ijklp}(1 - NABORT_{ijp}) + NABORT_{ijp} \right] x_{ijklp}$$

This equation covers the affect of total used weapons which is equal to the multiplication of load of each aircraft ( $\sum_{ijklp} LOAD_i$ ), the sum of the sorties attrited after they take-off and the sorties are not aborted in flight but attrited during the mission and total number of sorties assigned.

4. $$bu = \sum_b \left[ BUYWGT_b \left( \sum_i ACCOSTS_{ib} acbt_{ib} + \sum_j WPNCOSTS_{jp} wpnbt_{jb} \right) \right]$$

This constraint covers the importance of budget to the planner. It is calculated by the multiplication of objective function weight ( $BUYWGT_b$ ) for spending in budget $b$ with the money spent for each aircraft ( $\sum_i ACCOSTS_{ib} acbt_{ib}$ ) plus the money spent to buy for each weapon type ( $\sum_j WPNCOSTS_{jp} wpnbt_{jb}$ ).

### Objective function for time-scripted goals for a single period

This objective function minimizes the weighted sum of the proportions of each goal not achieved plus the sum of the tie-breaking weights

$$\min Z = \sum_{(k,c)\in cc(k,c)} \left(PPEN_{mct}\, pdiff_{kc}\right) + at + so + mu + bu$$

It is calculated by multiplying objective function penalty for not meeting the time-scripted goal for target class $c$ by the end of period $t$ ( $\sum_{(k,c)\in cc(k,c)} PPEN_{mct}$ ) with the proportion of kills below goal $c$ for target $k$ ( $pdiff_{k,c}$ ) plus the other penalty terms to break the ties. Model then minimizes this equation (Yost, 1996, pp. 25).

***Constraints:***

All CFAM variables are nonnegative, and all have simple upper bounds

$$x_{ijklp} \leq SR_i NDAYS_t TIMEAC_i \sum_b ACMAXBUY_{ib}$$

The meaning of this constraint is that the total number of sorties assigned should be less than or equal to the multiplication of sortie rate of each aircraft ( $SR_i$ ), number of days in time period $t$ ( $NDAYS_t$ ), number of aircraft $i$ scheduled to arrive by period $t$ ( $TIMEAC_i$ ), and maximum number of aircraft $i$ available for

purchase in budget $b$ ($\sum_{b} ACMAXBUY_{ib}$). Basically, it is equal to the sortie rate of each aircraft type times the number of days in that time period times the total number of each aircraft type.

$$pdiff \leq 1.0$$

Since $pdiff$ is a proportion, it must be less than or equal to 1.

$$wpnbt_{jb} \leq WPNMAXBUY_{jb}$$

The total number of weapons of type $j$ that can be bought in budget $b$ must be less than or equal to the maximum number of weapon that can be bought in budget $b$.

$$acbt_{ib} \leq ACMAXBUY_{ib}$$

The total number of aircraft of type $i$ that can be bought in budget $b$ must be less than or equal to the maximum number of aircraft that can be bought in budget $b$.

$$onhanduse_{j} \leq INVENT_{j}$$

The existing inventory of weapon $j$ must be less than or equal to the inventory of weapon $j$ on-hand.

**Goal Constraints**

$$\frac{\sum_{ijlp}(BDAREG_{k} EKS_{ijklp} NABORT_{ijp} x_{ijklp})}{GOAL_{ct} TOTTGT_{k}} + pdiff_{kc} = 1.0 \qquad \text{for all } (k,c) \in cc(k,c)$$

In this constraint the sum of the proportion of kills below goal $c$ for target $k$ ($pdiff_{k,c}$) plus the proportion of targets $k$ dead or in repair in time period $t$ must be equal to one. In Time Strike, targets, which belong to more than one class, have multiple positive ($pdiff_{k,c}$) differences. The developers of Time Strike have added this feature since they want a target which has an affect on many goals to gain multiple penalties in the objective function (Yost, 1996:26).

**Aircraft-sortie Constraints**

$$\sum_{iklp} x_{ijklp} / TSORT_{ijkp} \leq TIMEAC_i + \sum_b acbt_{ib} \qquad \text{for all } i$$

In this constraint, the total number of aircraft of each type must be less than or equal to the sum of the number of aircraft $i$ scheduled to arrive by period $t$ and the aircraft of type $i$ bought in budget $b$ in time period $t$. $TSORT_{ijkp}$ is the expected number of sorties that could be flown by an aircraft considering sortie rate , attrition rate and duration of the period (Yost, 1996:27).

**Aircraft Attrition Constraints**

$$\sum_{jklp} ATTR_{ijkp} * x_{ijklp} \leq MAXLOSS_i$$

This constraint calculates that total number of aircraft expected to be attrited must be less than or equal to the maximum losses of aircraft type *i* allowed.

### Weapon Use and Weapons Family Constraints

The first constraint counts the number of sorties that either drop bombs on a target or suffer attrition during an inflight weather abort. In both cases, the weapons are consumed. The second constraint addresses weapons that share common components, which is an important issue in munitions allocation. $FAMILYLIM_f$ gives the total number of available components, but this limit only applies to on-hand inventory. CFAM assumes purchased or arriving weapons are complete rounds (Yost, 1996:28).

$$\sum_{iklp} LOAD_l \left[ ATTR_{ijkp}(1 - NABORT_{ijp}) + NABORT_{ijp} \right] x_{ijkp} \leq onhanduse_j +$$

$$\sum_b wpnbt_{jb} + CUMARRIVE_J \qquad \text{for all } j$$

$$\sum_{j \in fc(j,f)} onhanduse_j \leq FAMLIM_f \qquad \text{for all } f$$

### Kills by Distance Constraints

$$\sum_{(i,j,l) \in r(i,j,l,d),p} (BDAREG_k EKS_{ijklp} NABORT_{ijp} x_{ijklp}) \leq \sum_{d' \leq d} TOTTGTS_{kd'} \qquad \text{for all } k,d$$

This constraint limits the possible combinations to targets according to the distance bands. They are cumulative to permit the long-range flights to kill close-in targets. Since there is no explicit definition of distance bands, this feature eliminates a vast number of variables (Yost, 1996:29).

### Weather Constraints

$$\sum_{(j,p)\in wc(i,j,p,w),kl} x_{mijklpt} \geq HISTFORECAST_w \sum_{jklp} x_{ijklp} \qquad \text{for all } i,\ w$$

This constraint limits the number of sorties assigned with the average weather forecast ($HISTFORECAST_w$) (Yost, 1996:26).

### Weapon Qualification Constraints

$$\sum_{(j\in qc(j,q),klp} x_{ijklp} \leq PROPORTION_{iq} \sum_{jklp} x_{ijklp} \qquad \text{for all } (i,\ q) \text{ with proportion} > 0$$

This constraint limits the number of sorties assigned if only a certain proportion of an aircraft's aircrew are qualified to deliver a weapon, or only a certain proportion of an aircraft type are equipped to drop a weapon (Yost, 1996: 30).

CFAM offers a wide array of options of formulating. The use of priority classes and goals allows the modeler to differentiate targets. It requires a great deal of data however to drive the options in the model.

## 2.7. Comparison of the Models

All the models reviewed have good and bad attributes, according to their development purposes. Heavy Attack is the most aggregated model, allocating aircraft to targets without considering weapons and aircraft attrition rates. In addition, it does not have a budgeting constraint. The only objective in Heavy Attack is to maximize TVD. Because of the aggregation in the model, it runs very fast but ignores many details.

The biggest disadvantage of TAM is its weather assumption. TAM assumes that weather is known with certainty. The model uses a weather distribution to predict the amount of each sortie type. TAM optimizes globally across time as well. All of these assumptions make TAM a very large optimization model that needs more time to solve the expected scenarios of future conflicts.

Mixmaster was developed due to the unsatisfactory results of TAM. This aggregate model includes fewer parameters than TAM, which means less computation time. Unfortunately, the model does not have any constraint related with the cost of the operation. Therefore, Mixmaster does not answer questions about the cost of the operation while optimizing the TVD.

CTEM is a conventional derivative of the widely used Arsenal Exchange Model (AEM). CTEM is more of an optimization system than a specific model, since the user can alter the objective and constraints according to his intents. CTEM, on the other hand, was built to handle the allocation problem, and it did not contain some of the capabilities necessary for requirements and trade of analysis.

CFAM is a consolidation of these models. While it retains some of the objectives common to the three existing models, it also modifies them. CFAM offers *time-scripted*

*objective* where the user is evaluating a specified schedule for a campaign. However, users often want to determine the time necessary to achieve campaign objectives, so CFAM offers another objective function called *phase-goal objective.* CFAM has a different aspect for target classes than the previous models. Since CFAM is a fairly new model its limitations will be seen more accurately in future applications.

### 2.8. Results of the Literature Review

As a result of the literature review, it was learned that a force structure model should cover:

- time,
- cost of buying an aircraft and weapons,
- budget and attrition factors.

The model should also be able to incorporate decision-makers' campaign objectives. This chapter presented a review of the key models used to model campaigns over the years for the USAF. Based upon this review, a model for force structuring in a moderately-sized NATO country will be developed in Chapter 3. Table 1 summarize the key features of each model.

**Table 1. Comparison of the Models**

| | *HEAVY ATTACK* | *TAM* | *MIXMASTER* | *CTEM* |
|---|---|---|---|---|
| Objective function | Nonlinear tgt.val. | Linear tgt.val. | Linear tgt.val. | Linear tgt. val + goal + multiple |
| Sortie dimensions | Aircraft + target | Aircraft + weapon+ target + loadout+ time + distance+ weather | Aircraft + weapon+ target + loadout+ distance +weather | Aircraft + weapon+ target + loadout+ distance + weather+ user defined |
| Target Dimensions | type | Type + distance band | Type + distance band | Type + distance band + user defined |
| Time Approach | Myopic | Global | Myopic | Myopic |
| Miscellaneous | BDA + wether unknown | Weather known + budget + attrition affects sorties | Weather known+ attrition affects sorties | BDA+ weather known + Budget + SEAD + attrition affects sorties |

# III. METHODOLOGY

## 3.1. Approach

The basic intent of this effort is to develop a mathematical model which will assist senior decision-makers in developing an air force's force structure composition for a moderately-sized NATO country. "*Do we have sufficient amounts and variety of weapon systems to survive any expected conflict situation*" is the paramount question that always faces military decision-makers.

In its most general form, this is a *resource allocation* problem where the objective function is to achieve the maximum value of total targets destroyed given a mix of aircraft, munitions, targets and time phases. Given the aggregate nature of the force-structuring problem, coupled with the uncertainty in the data, linear program was chosen as a modeling and solution mode. This choice allows extensive sensitivity analysis to be applied to the analysis of the force structuring problem.

## 3.2. General Overview of LP

Linear programming (LP) attempts to minimize or maximize a linear function, subject to linear equality or inequality constraints. LP has been successfully used in a broad range of application areas since it was developed by George B. Dantzig and others in 1947. Its wide application to a variety of areas is due to its ability to model large and complex real-world problems and to solve them in a reasonable amount of time. It was well understood by the USAF that there was a need of planning and coordination among

different projects to effectively allocate scarce resources. This allocation problem was the initiative idea of Project SCOOP (Scientific Computation of Optimum Programs) leaded by Dantzig in 1947. As a result of the SCOOP project, Dantzig developed the *Simplex Method* (Bazaraa and others, 1977:vii.). To formulate a problem as a linear program, the following assumptions are needed:

1. *Proportionality* : Considers the activities independent of others.
2. *Additivity* : Contribution of any variable to the objective function is directly proportional to its *cost coefficient* ($c_j x_j$) and contribution to the $i$th constraint is directly proportional to its *technological coefficient* ($a_{ij} x_j$); that is, there is no interaction term.
3. *Divisibility* : Each decision variable is allowed to assume fractional values.
4. *Deterministic* : Each parameter (objective function coefficient, right-hand side, and technological coefficient) is assumed to be known with certainty. If there is any probabilistic or stochastic element in the problem, it is assumed that this element is included in to the model by the use of fixed values (Bazaraa *et all*, 1977:3).

### 3.3. Software and Sensitivity Analysis

In this study, the General Algebraic Modeling System (GAMS) was used to perform the analyses. The programming features of GAMS allow some optimization problems to be expressed independently of the data it uses. GAMS provides an array of ways to track the solution steps of the formulation for each variable, and for each constraint as well. Portability is another reason for choosing GAMS, since GAMS

models can be solved on different types of computers without any change (GAMS User's Guide, December 1998:2).

LINDO software was used to perform parametric analysis for the aircraft cost values (LINDO User's Manual 5.0, 1991). LINDO was chosen since GAMS does not provide direct parametric analysis function. The linear programming sensitivity analysis involves changing one parameter at a time in the original model to check its effect on the optimal solution. By contrast, *parametric linear programming* involves the systematic study of how the optimal solution changes as several of the parameters change *simultaneously* over some range. This study can provide a useful extension of sensitivity analysis to check the effect of correlated parameters. However, a more important application is the investigation of *tradeoffs* in parameter values.

### 3.4. Explanation of the Suggested Approach

While a wide array of models have been developed to address force allocation, none appeared to fit the specific aspects of a moderately-sized nation. Key elements were drawn from each model reviewed to support the projected needs of a moderately-sized NATO country. The model developed using this approach is presented in this chapter.

The approach used in the study is illustrated with a small, notional example. This small example is used for ease of discussion. The basic decision variable is the *Number of Sorties Flown by Each Proposed Aircraft Type* ($X_{amkt}$) against each hypothetical target with given munitions in any one of the phases of the conflict. The objective is to *Maximize the Value of the Designated Targets Destroyed* based on the total number and

mix of *aircraft, munitions* and *targets* selected. There are four basic constraint types associated with *Total Number of Aircraft for the First Phase*, *Total Number of Aircraft for the Second and the Third Phases, Total Number of Munitions and Total Number of Targets*.

To incorporate the decision-makers' campaign goals and the operational limitations of an air force, a binary parameter $HAK_{amkt}$ is defined. To determine the number of aircraft needed to be purchased, the variable *BUY* is defined in the first phase, since it is given that all procurement decisions must be made before the beginning of the conflict.

The *SEM* parameter is defined for each target indicating the percentage of the target to destroy. For the example, *SEM* is a constant number of 1.2 allowing for a 20% overestimate for each target group to assure that target group is killed completely. These additional strikes increase the number of targets in that group to compensate for the possible gaps between the real yield values of each sortie type, and the ones extracted from JMEM. In addition, the *SEM* parameter also helps, to a certain extent, to capture both Battle Damage Assessment (BDA) and re-generation capabilities of the enemy. Since the total number of targets is overestimated at the campaign theater, the model allocates more aircraft and weapon resources than actually required, but as a return, increases the likelihood that the targets are destroyed. This helps to account for the "fog of war".

The suggested model has similarities to existing models. These similarities include the use of target values in the objective function, as in TAM or Mixmaster, and

the decision variable definition. In the model, the decision variable has four indices including *aircraft type, munitions type, target groups,* and *phases.*

One of the differences in the model is the target definition. Similar types of targets, which are located at the same geographical area in the campaign theater, are grouped under the same target index. For instance, 10 SA-6 SAM sites positioned around the enemy runway can be considered as the first target group T-1 or T-2 may represent enemy munitions facility located at 64'22''N - 119'12''E, which includes 30 munitions depots.

Each target group is considered individually, with its location and assigned military importance/value (*TVAL*) in each phase. Since each target group is composed of similar types of targets, the same yield values and attrition rates will be valid for the entire group. This idea helps to aggregate distance bands in the model and to capture the dynamic nature of the air campaign by assigning different target values in each phase, rather than assigning fixed *TVALs* for the entire conflict. For instance, even though they are the same type of targets, SAM sites around an enemy runway that is close to the front line of the battlefield, may have higher TVAL than the SAM sites around an enemy runway deep in enemy territory.

The other basic difference is the consideration of time in the model to capture the weapon usage and aircraft attrition. TAM has this feature but incorporates it through the use of additional variables in the formulation. Since it is *time-myopic,* Mixmaster requires an analyst to calculate the changes in the inventory levels (Dengur, 1992: 2-4). The model calculates the total attrition for each aircraft type and weapon usage for each

individual target, considering attrition rates and bomb usage against each target in each phase.

In addition, munitions requirements are defined individually for each aircraft/ munitions/target combination to capture the partial weapon load option for some targets. That is, to increase the combat radii or to carry additional self-defense equipment, partial loads can be chosen as an option for a mission. For example, F-5 aircraft cannot be assigned against T-9 since F-5 cannot carry enough fuel to fly to that target with a full weapons load. However, with a partial weapons load, this distance constraint can be overcome. This feature contributes to the additional flexibility to the model.

Another major difference from previous models is the use of parameter, the $HAK_{amkt}$, to capture both decision-makers' campaign goals and operational limitations of an air force. All of the sortie types are assigned 0-1 values to specify *which* target will be attacked in *which* phase and with *which* weapon by using the $HAK_{amkt}$ parameter based on the decision-makers' campaign goals.

If the campaign planners want to attain air supremacy at the beginning of the war, they may prefer certain target types (i.e. runways, SAM sites and command centers) be attacked and completely destroyed in the initial phase of the conflict. To perform this objective each sortie type is evaluated and classified as to whether that sortie type is feasible for that target or not. This process is performed during the preparation of the prioritized target list.

Decision-makers also have an option of assigning only certain types of aircraft or munitions to any target group in the suggested formulation. This feature also helps to carry a certain type of campaign against the enemy. For instance, although there is an

option of choosing gravity bombs, which are less expensive than smart bombs, due to their precision problems decision-makers may prefer to use *Maverick* against a particular target group if the target group is very close to a hospital and *collateral damage* is a concern.

On the other hand, campaign planners may want certain types of targets to be attacked in consecutive phases to make sure these targets are completely destroyed, since assigning 100% correct Battle Damage Assessment (BDA) rates still remains an open research area. Another point, which must be considered, is the *regeneration or reconstruction* ability of the enemy. In the suggested model, if a target is attacked once in any phase than it is assumed to have been killed and will not be targeted again until the next phase.

Consider that the model destroyed an enemy munitions depot facility in the second phase of the 7 days conflict. The question that is to be asked is *if the enemy is capable of constructing some of these buildings for the third phase or not.* If the answer is YES then can the enemy regenerate the capability within the timeframe of the scenario? *How many buildings can be built in 7 days?* The model allows the planner to capture this feature by specifying the number of targets in each target group for each phase. That is, the same target group might include different numbers of targets in different phases. This feature also captures the mobility of some target types such as mobile SAMs in the campaign theater. One of the major problems for the pilots flying strike packages over Kosovo was correctly spotting the exact location of the mobile SAMs.

In terms of the operational limitations of an air force, some types of weapon platforms may not be able to fly all the sortie types; F-5s cannot carry smart bombs, so campaign planners cannot assign F-5s to targets calling for smart bombs. This is similar to not having the option of assigning F-5s to a far target since their external tanks cannot be on-board if that target is required to be attacked with a full weapons load. This limitation can be eliminated by a partial weapons load which the model allows the planner to consider by defining different weapons loads ($B_{amk}$) for each combination of aircraft/munitions/target.

To determine how many aircraft are required to destroy all the planned targets, the model uses the variable, $BUY_a$, to decide *which aircraft type* and *how many* to buy. The suggested model considers the cost of buying an additional aircraft and its effectiveness while trying to destroy all the targets.

### 3.5. Explanation of the Algorithm

The objective function is to maximize the total target value destroyed. The model attempts to match the highest value target with weapon platforms configured to result in the highest yield value for that particular target. Each target is given a military value (*TVAL*) based on the phase of the conflict and its location. These values are relative to other values in the theater and subjective since planners assign TVALs according to decision-makers' campaign objectives (ASC/XREWS, 1994: n. pag.).

A higher target value represents higher importance and the planners want the model to select the higher priority targets in a phase first. Decision variables reflect the number and type of aircraft and munitions needed for each target. *Number of Sorties*

*Flown by Each Proposed Aircraft Type* ($X_{amkt}$) will be a continuous variable. For instance, the model may assign 26.3 sortie of AIRCRAFT-1 aircraft loaded with Maverick, against target group T-1 in phase 2 or 115.74 sortie of F-5 aircraft, loaded with Mk-82, against target group T-15 in phase 3. The planner will then choose whether to send 26 AIRCRAFT-1 or 27 AIRCRAFT-1 aircraft to that target, which is the part of a mission planning process. At the aggregate planning level of force structuring, however, these continuous variables are sufficient.

In the suggested model, the $BUY_a$ variable determines *how many and which type* of aircraft should be purchased subject to the cost of buying new aircraft. Although there is no explicit variable which tells *how many and what type of weapons* should be procured to achieve the desired campaign objectives, the model still can be used to find an answer for this question. If there is a difference between the real inventory level and the assumed level then this difference will show whether there is a need to buy additional weapons or not. The suggested model is capable of calculating how many aircraft are attrited and what the usage levels of each munitions types are for each target group in each phase as well. The model also calculates the number of targets attacked in each phases. Of course a munitions $BUY_a$ variable could be added.

### 3.5.1 Target Values

There has been a great deal of discussion about using Target Values since it is hard to assign them objectively. Target values are often subjectively derived and, perhaps, may be manipulated by those executing a model. They are the most subjective input in this formulation; however, the methodology does provide an objective process.

On the other hand, the use of subjective values might be considered a necessity since it is the only way to incorporate the decision-makers' expectations and real-world constraints that cannot be accommodated by the model's formulation. There are other factors which make the use of target values inevitable. For instance, combatant morale may change the target destruction priorities and senior decision makers and analysts are often the only credible sources for evaluating these factors.

Although the TVALs are subjective, it is believed that using target values is acceptable. Note that target values can also be used as "radio knobs", since the model is not capable of determining the importance difference among the existing targets. That is, the model can kill 10 bridges of value 20 instead of killing 2 Command and Control Center ($C^3$) of value 100 and still can get the same Target Value Destroyed of 200. To prevent this problem, the planner can adjust the Target Values so that the model selects the most appropriate targets (e.g. $C^3$, not the bridges).

**Table 2. Subset of Target List for Illustration Purposes**

| Target Description | Time Periods | Target Values | Attrition Rates |
|---|---|---|---|
| K1Runway Located at<br>65'25''N 120'12''W | 1-2-3 | 200-200-100 | A/C-1: 0.19 / 0.16 / 0.12 -Mk-82<br>A/C-1: 0.12 / 0.08 / 0.06 -Durandal<br>F-4 : 0.25 / 0.22 / 0.19 -Mk-82 |
| K2 Runway Located at<br>64'22''N 119'12''W | 1-2 | 150-80 | A/C-1: 0.14 / 0.12 / 0.10 -Mk-82<br>F-4 : 0.21 / 0.15 / 0.13 -Durandal<br>F-5 : 0.38 / 0.36 / 0.25 -Mk-82 |

Table 2 shows that the target values for T-2 are 150 and 80 in phase 1 and in phase 2 respectively. If A/C-1 aircraft is assigned to target group T-2 then the expected attrition for that sortie is 0.14, 0.12 and 0.10 for phase 1, phase 2 and phase 3 respectively. On the other hand, if F-4 aircraft is assigned to that target then the expected attrition is 0.21, 0.15 and 0.13 for phase 1, phase 2 and phase 3 respectively. The attrition rates of the sorties flown by F-4s are higher than the attrition rates of the sorties flown by A/C-1As for this target.

### 3.5.2. Target List

One of the basic differences between the reviewed models and the suggested model stems from the definition of targets. Each target will be evaluated individually. For instance, target group 1 is enemy SAM sites, and *must* be attacked in phase 1, phase 2 and phase 3.

**Table 3. The Number of Targets in Each Phase**

| TARGETS | PHASE 1 | PHASE 2 | PHASE 3 |
|---|---|---|---|
| **T-1** | 20 | 15 | 10 |
| **T-2** | 42 | 16 | 14 |
| **T-3** | 12 | 8 | 5 |
| **T-4** | 32 | 15 | 12 |
| **T-5** | 60 | 40 | 15 |
| **T-6** | 50 | 40 | 30 |
| **T-7** | 25 | 20 | 15 |
| **T-8** | 30 | 30 | 20 |
| **T-9** | 40 | 30 | 20 |
| **T-10** | 100 | 80 | 50 |
| **T-11** | 35 | 40 | 25 |
| **T-12** | 25 | 50 | 32 |
| **T-13** | 45 | 25 | 20 |
| **T-14** | 25 | 20 | 10 |
| **T-15** | 60 | 50 | 55 |

This approach has some advantages over the previous models. Since each sortie is defined as a combination of aircraft, munitions, target and phase, one can define different *attrition rates*, *target values* and *bomb requirements* for each sortie type.

Table 3 shows an illustrative example of target list. For instance, target group T-2 includes all the Sam sites located at the same area. There are 42 SAM sites, 16 SAM sites and 14 SAM sites in phase 1, in phase 2 and in phase 3 respectively. This allows to cover re-generation capability of the enemy to a certain extend by defining different number of targets for each phase.

### 3.6. Comparison of the Models

The suggested model is developed for force structuring purposes with the inclusion of the budget constraint. The model considers the cost of buying an aircraft while deciding whether or not there is a need to buy an aircraft to destroy all the designated targets in the planning scenario. The formulation of the model allows the decision-makers to test an array of different scenarios with many different allocation plans to end up with the right mix of weapon systems and munitions. While the illustrative example in Chapter 4 simply covers the purchase price of aircraft, the discontinued life cycle cost of the system could be used.

Table 4 shows a comparison of the suggested model and the aircraft allocation techniques from the models.

## Table 4. Comparison of the Proposed Model with the Previous Models

| | ***HEAVY ATTACK*** | ***TAM*** | ***MIXMASTER*** | ***CTEM*** | ***SUGGESTED FORMULATION*** |
|---|---|---|---|---|---|
| Objective function | Nonlinear Target Values | Linear Target Values | Linear Target Values | Linear Target Values. goal + multiple | Linear Target Values |
| Sortie dimensions | Aircraft+ target | Aircraft+ weapon+ target+ loadout+ time+distance+ weather | Aircraft+ weapon+ target+loadout+ distance+ weather | Aircraft+ weapon+ target+loadout+ distance+ weather+ user defined | Aircraft+ weapon+ target groups+ time |
| Target Dimensions | Type | Type+distance band | Type+distance band | Type+distance band+user defined | Type+ time phases |
| Time Approach | Myopic | Global | Myopic | Myopic | Time Phases |
| Miscellaneous | BDA+wether unknown | Weather known+budget +attrition affects sortiessorties | Weather known+ attrition affects sorties | BDA+wether known+ Budget+SEAD+ attrition affects sorties | Weather known+ Budget+ Attrition effects+sorties+ BDA |

### 3.7. Model Assumptions

The assumptions for the proposed model are given below:

1. The conflict may contain several phases, each of different duration.
2. Target values are assigned in the target prioritization phase according to the their type, location and the phases that they are required to be attacked. These values are determined to reflect the decision-makers' campaign objectives and are considered an input to the model.
3. The suggested model will be run for both GOOD and BAD weather conditions.
4. The enemy is unable to launch offensive operation. They will defend their assets, however. This will cause attrition, which the model incorporates.
5. Sortie rates ( $SR_a$ ) are assumed constant during the conflict.
6. In target prioritization phase, aircraft types that can be assigned against each target groups are determined according to target location, target defense and desired damage on target. For instance, F-5 type of aircraft are not assigned to enemy runways since neither are they capable of flying long-range missions nor carrying Durandal bombs. The feasible sortie assignments are also specified in this period according to decision-makers' campaign goals by the use of $HAK_{amkt}$ parameter.
7. All of the procurements must be done before the beginning of the conflict.
8. Only Air-to-Ground portion of the air campaign is considered for this particular study.

### 3.8. Suggested Formulation

***Indices:***

| | | |
|---|---|---|
| *a* | aircraft type | AIRCRAFT-1 / F-4 / F-5 |
| *m* | weapons | Mk-82 / Mk-84 / Durandal / Maverick |
| *k* | target groups | for instance SAM sites around runway located at …N…E, with a Target Value… for the first period…for the second period, … for the third period; if it is supposed to be bombed in each time period. |
| Example: | | T-1 is a SAM site target group, which includes 15 SA-6 sites around a enemy runway and will be attacked in P-1, P-2 and P-3. TVAL for the first time period is 200, for the second time period 200, but for the third time period it is 1. Target types are Aircraft shelters, Runways, SAM Sites, Command Centers, Munitions Depots, Factories, Bridges and Tank Battalions. |
| *t* | | Time phases of the conflict.<br>phase 1 (P-1): First phase of the conflict. (3 days)<br>phase 2 (P-2): Second phase of the conflict. (7 days)<br>phase 3 (P-2): Third phase of the conflict. (10 days) |

Note that the actual duration and the number of phases will be dependent upon the operational plan. Phases do not have to be of the same length. Decreasing the duration of each phase can increase the reliability of the model. On the other hand, there is trade

off between the resolution and increasing the number of phases in the model, which will affect the solution time.

***Variables:***

$X_{amkt}$ number of sorties flown by each aircraft type *a*, loaded with munitions *m*, against target $k$, in phase $t$. For instance, $X_{2123}$ represents the number of sorties flown by F-4 aircraft, loaded with Mk-82, against target 2, in phase 3. If the solution says $X_{2123} = 5$, it means that planner is suggested to assign 5 sorties which is a combination of F-4 aircraft, loaded with Mk-82, against target group T-2 in phase 3 to attain the desired amount of destruction.

$YIELD_{amkt}$ yield (fractional target kills) per sortie, calculated based on the mission effectiveness and attrition. $YIELD_{amkt}$ values are extracted from the JMEM manuals by providing aircraft type, flight profile, target type and weapons load.

$TVAL_{kt}$ target value assigned to target $k$, in phase $t$. The same target may have different importance in different time phases.

$HAK_{amkt}$ a binary parameter which specifies the allowable/feasible sortie types.

$SR_a$ daily sortie rate of a single aircraft type $a$.

$SEM$ a constant (1.2). This parameter serves for two purposes: First one is that to capture the possible differences between JMEM and the real life $YIELD_{amkt}$ values. This parameter makes sure that target group is killed

completely since we increase the number of targets by 20%percent. The second one is capturing BDA and re-generation capability of the enemy.

$EA_{amkt}$ expected attrition for a single sortie $X_{amkt}$ ($EA_{amkt}$ =0.0003 means the planner expects to lose 3 aircraft if 1000 aircraft is lunched).

$ACCOST_a$ cost of buying an aircraft

$BUDGET$ total amount of budget allocated for aircraft purchases

$TOTAC_a$ total number of aircraft type *a*.

$TOTWPN_m$ total number of munitions *m*.

$TOTTGT_{kt}$ total number of targets *k* in each phase *t*.

$TS_{amkt}$ total number of sorties that *can* be produced by a single aircraft type $a$, loaded with munitions $m$, against target $k$, in phase $t$. The total number of sorties that could be produced during this period can be as follows:

$$\sum_a \sum_m \sum_k \sum_t TS_{amkt} = \frac{1-(1-EA_{amkt})^{SR_a NDAYS_t}}{EA_{amkt}}$$

$NDAYS_t$ is the duration of phase *t*; how many days there are in one time phase. For instance, aircraft type: AIRCRAFT-1 / Phase: P-3 / $NDAYS_3$ : 10 / $EA_{1313}$ : 0.01 / Target: k1 / Munitions: Durandal / $SR_{F-16}$ : 2

$$TS_{amkt} = \frac{1-(1-0.01)^{2*10}}{0.01} = \frac{0.18209}{0.01} = 18.209$$

sorties can be produced by a single Aircraft-1 for that target k1 instead of 20 in phase 3.

$$1 - ATTRIT_{amkdtw}$$

is the success of a single sortie or the survivability of a single sortie. (1-0.01=0.99).

$$(1 - ATTRIT_{amkdtw})^{SR_a NDAYS_t}$$

is the percentage for a single aircraft type $a$ of producing successful sorties during 20 days. $0.99^{20} \cong 0.8179$. It means 18% of the total sorties (or 18 out of 100 aircraft) is expected to be lost during 20 days period.

$$1-(1 - ATTRIT_{amkdtw})^{SR_a NDAYS_t}$$

is the percentage for a single aircraft type $a$ of producing unsuccessful sorties during 20 days. ($1 - 0.8179 \cong 0.182$). That is 18% of the aircraft will not be able to come back..

$$\frac{1-(1 - ATTRIT_{amkdtw})^{SR_a NDAYS_t}}{ATTRIT_{amkdtw}}$$

is the total number of sorties that a single aircraft type $a$ *can* produce during 20 days. $0.182 \div 0.01 \cong 18.2$ sorties can be produced by a single aircraft type $a$.

## Objective Function

$$MaxTVD = \sum_a \sum_m \sum_k \sum_t X_{amkt} YIELD_{amkt} TVAL_{kt} HAK_{amkt}$$

To maximize the Total Target Value Destroyed, the number of sorties flown ($X_{amkt}$), the yield of that sortie ($YIELD_{amkt}$) and target value assigned to target $k$, in time $t$ ($TVAL_{kt}$) are multiplied by type and then summed. By eliminating infeasible sortie combinations, the $HAK_{amkt}$ parameter reduces the problem size. It assists in preprocessing for feasible sortie allocations.

***Constraints:***

1. Total Number of Aircraft for the First Phase of the Conflict

$$\sum_a \sum_m \sum_k \sum_{t=1} \left( \frac{X_{amkt}}{TS_{amkt}} \right) HAK_{amkt} \leq TOTAC_a + BUY_a \qquad \text{for each } a$$

If we divide the total number of possible sorties flown ($X_{amkt}$), by the total number of sorties that a single aircraft type $a$ ***can*** produce ($TS_{amkt}$) we end up with the Total Number of Aircraft that we need for the first period, which is less than or equal to the initial inventory plus any aircraft by type purchased prior to the first period ($BUY_a$).

2. Total Number of Aircraft for the Second and Third Phases of the Conflict

$$\sum_{a}\sum_{m}\sum_{k}\sum_{t\geq 2}\left(\frac{X_{amkt}}{TS_{amkt}}\right)HAK_{amkt} \leq TOTAC_{a} - \sum_{t-1}\left[\sum_{mk} X_{amkt} EA_{amkt}\right] + BUY_{a}$$

for each $a$ and $t = 2,3$

Since attrition ($EA_{amkt}$) will affect the total number of aircraft available for each phase, we subtract the number of aircraft attrited in the previous phase from the total number of aircraft of that phase and add the amount of new purchased aircraft. The multiplication of the number of sorties flown in any phase with the expected attrition rate of that sortie type will give us the total number of aircraft attrited in that phase.

$$\sum_{a}\sum_{m}\sum_{k}\sum_{t} TS_{amkt} = \frac{1-(1-EA_{amkt})^{SR_{a}NDAYS_{t}}}{EA_{amkt}}$$

This equation gives the total number of sorties that an aircraft of type $a$ can produce in each phase. This parameter simply charges each sortie for the fraction of the aircraft that is "consumed" each time that sortie is chosen. In fact, if the conflict is supposed to be over in a short period of time, the total sorties are constrained by the number of sorties per day. If the conflict is assumed to be longer, the constraint is driven by the attrition rate. For instance, sortie rate for

AIRCRAFT-1 = 2, for F-4 = 1.5, for F-5 = 1. If we think about the third phase, which includes 10 days, one single AIRCRAFT-1 aircraft is supposed to produce 2 times 10 equal to 20 sorties. Unfortunately, attrition of some of these sorties is inevitable.

3. Total Number of Weapons

$$\sum_a \sum_k X_{amkt} B_{amk} HAK_{amkt} \leq TOTWPN_m \qquad \text{for each } m \text{ and } t.$$

$B_{amk}$ is the number of bombs (weapon load) per aircraft type $a$, loaded with munitions $m$ for each target. If we multiply the total number of sorties flown to that particular target with the number of weapons carried in that flight, we end up with the total number of weapons necessary for that scenario. For the initial analysis, it is assumed that all the weapons used in the conflict are in inventory.

4. Total Number of Targets

$$\sum_a \sum_m \sum_k \sum_t X_{amkt} YIELD_{amkt} HAK_{amkt} \leq TGT_{kt} SEM \qquad \text{for each target k.}$$

If a target is required to be killed completely, the multiplication of the total number of sorties flown against a particular target group with a specific yield value of that sortie ($YIELD_{amkt}$) must be smaller than or equal to the total number of targets in that target group times the desired over strike rate (SEM).

5. Total Budget Constraint

$$\sum_{a} ACCOST_a BUY_a \leq BUDGET$$

The cost of a single aircraft type *a* ($ACCOST_a$) times the number of aircraft of type *a* bought ($BUY_a$) must be smaller than or equal to the allocated *BUDGET*. While not capturing all the possible features of the models reviewed, the proposed model does provide an array of optimum conditions to force structuring. The basic model is illustrated in the next chapter using a small, notional example of a single theater campaign. The model, however, can easily be expanded to consider the entire requirements of an air force. Through the use of the options illustrated in Chapter 4, a force structure can be analyze for a moderately-sized nation at the aggregate planning level.

# IV. ANALYSIS

## 4.1. Introduction

This chapter shows the model's weapon-allocation plan for a small-scale air campaign scenario. To learn if the nation under study has sufficient amounts of weapon systems and munitions, the suggested formulation is tested for different weather and combat scenarios beginning with the current allocated number of aircraft and munitions types.

This hypothetical air force is composed of AIRCRAFT-1A, AIRCRAFT-1D, F-4 and F-5 aircraft. In this notional scenario there are two different force allocation plans to reflect the assumptions of two different Tactical Force Commands which can be assigned to this conflict situation. According to the first plan, allocated air forces include 50 AIRCRAFT-1As, 50 F-4s and 50 F-5s. For the second plan 50 AIRCRAFT-1D, 50 F-4s and 50 F-5s are allocated to this notional conflict situation. It is known that AIRCRAFT-1Ds are 30% more effective than AIRCRAFT-1As, since their survivability is increased due to on-board self-defense equipments *i.e.* Radar Warning Receiver (RWR) which result in increased yield values.

For this example scenario, four classes of weapons are considered; 10000 Mk-82s general-purpose bombs, 8000 Mk-84s general-purpose bombs, 5000 Durandal runway munitions and 5000 Maverick air-to-surface missiles. The cost of AIRCRAFT-1A/D and

F-4 aircraft is 30 units and 10 units respectively where the total allocated budget is 800 units. The scenario also includes 15 target groups which include enemy runways, SAM sites, command and control centers, factories and bridges to name a few.

It is assumed that the nation under study will not be able to re-arm or replace platforms during the short term conflict (20 days) under consideration. It is therefore necessary to structure the nation's forces to sustain it through the conflict and provide for a victory.

The first allocation plan assumes good weather and the attainment of air supremacy as the first scenario. These conditions result in low attrition rates. The same allocation plan will then be tested for bad weather and no air supremacy as the second scenario. Attrition rates in the second scenario are higher than the first scenario. The cost of buying aircraft will then be added into the model with a budget constraint. The bad weather, no air supremacy condition will be tested with new cost-added model for varying cost levels of F-4 aircraft. The second allocation plan will then be tested for the same scenarios.

The mission planners assign all aircraft types to each target in the target prioritization phase according to aircraft capabilities, target defense and the level of damage desired on target. The decision- makers' campaign goals are also included in this prioritization phase. Target values reflect campaign objectives. They are defined individually for each target and for each phase. The same type of targets may be assigned different target values even in the same phase due to the tactical or strategic importance of their geographical locations. All this flexibility allows the decision-makers to capture as many dynamic aspects of the campaign theater as possible.

Notional yield values reflect each sortie's fractional kill values. Attrition rates are defined separately for each sortie ($X_{amkt}$). Therefore, depending on aircraft specific the capabilities, each aircraft type has a different chance of survival against the same target.

This probability of survival is composed of the probability of survival against both enemy air and ground threats. As the model moves through the phases, survivability increases on the assumption the modeled forces destroy more ground targets and gain and maintain air supremacy over the campaign theater. The probability of survival depends on many factors, including aircraft speed, maneuverability, radar capabilities, self-defense systems *i.e.* Radar Warning Receiver (RWR), on-board electronic countermeasures, and perhaps the most important factor, personnel training. Of course, other functions will also affect estimated survivabilities.

### 4.2. Results of the First Scenario

In the first scenario, the weather is assumed good and air supremacy has been attained. That is, expected attrition rates for each sortie type will be small. The model used all the allocated aircraft, munitions types in varying amounts, and destroy all the targets in each phase. Recalling that the model is an aggregate model, the objective that was accomplished is a target value of 193680 with a 100% target destruction rate. The model used all of the Mk-82 and Mk-84 bombs to accomplish the mission. The total number of attrited aircraft is 11.15 AIRCRAFT-1A, 6.05 F-4 and 12.28 F-5 aircraft during the entire conflict. The numerical results are shown in Table 5 and Table 6. The sortie allocations can be found in Appendix E.

In terms of the allocation decisions, the study interpreted the marginal values of the constraints on aircraft types. If any of the marginal values were positive, it would imply that there is a gain to be obtained from having of that type of aircraft.

For instance, assume that the marginal value of AIRCRAFT-1A is 50 units. That is, if we have an option of adding one more AIRCRAFT-1A to the inventory, its contribution to the overall objective function total value is 50 units. Hence, if the decision-maker wants to achieve an objective value of 194180, this would require 10 more AIRCRAFT-1A aircraft assuming other aircraft levels are fixed, if the change is within the allowed range of variation. For the initial scenario, none of the marginal values of aircraft types was positive.

**Table 5. Aircraft-Weapon Allocations for the First Scenario**

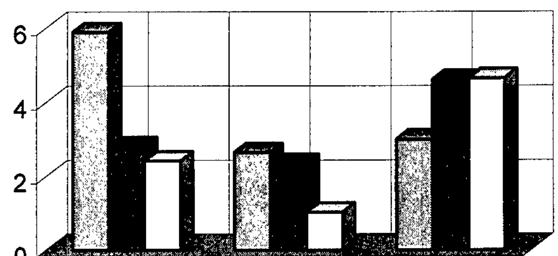
| Aircraft | Total Usage | Total Attr. | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 32.41 | 11.15 | 2356.08 | 5791.64 | 67.52 | NONE |
| **F-4** | 20.22 | 6.05 | 6441.49 | NONE | NONE | 217.08 |
| **F-5** | 20.38 | 12.28 | 1202.41 | 2208.35 | NONE | NONE |
| **TOTAL** | | 29.49 | 10000 | 8000 | 67.52 | 217.08 |

The suggested model used all aircraft and weapon types at different levels. The total usage indicates that the total number of aircraft needed to fly the required number of missions to destroy all of the designated targets. That is, the allocated number of aircraft, which are 50 for each aircraft type, is enough to accomplish the campaign goals in GOOD weather with AIR SUPREMACY. The model used all of the Mk-82s and Mk-84s but only a small portion of the smart bombs. Note that the number of aircraft loss in each phase is not very high due to low attrition rates. Again, these low attrition rates are

a function of the assumed conditions of good weather and the attainment of air supremacy.

**Table 6. Aircraft Attrition in Each Phase**

**Aircraft Attrition in Each Phase**




| | A/C-1 | F-4 | F-5 |
|---|---|---|---|
| 1st phase | 5.89 | 2.66 | 3.01 |
| 2nd Phase | 2.82 | 2.36 | 4.61 |
| 3rd Phase | 2.43 | 1.03 | 4.65 |

This initial analysis indicates that the decision-makers have enough weapon platforms and munitions, in aggregate, to destroy all the designated targets if the weather is good and air supremacy has been attained. Table 6 indicates that the anticipated aircraft losses per phase of the conflict. A conservative estimation may be to round each value up, although this could make the totals slightly higher than actual limits (always a problem in disaggregating aggregate values). The first scenario established that sufficient forces are available under ideal conditions. The second scenario investigates the effects of less than ideal conditions; a proxy for the “fog of war”.

## 4.3. Results of the Second Scenario

According to the second scenario, the weather is BAD and AIR SUPREMACY has not been attained. To reflect this situation high attrition rates are expected for each sortie type. Solving this model resulted with a total target value of 172587.03 with a target destruction rate of 88.10% with $SR_{A/C-1} = 3$, $SR_{F-4} = 2.5$ and $SR_{F-5} = 1.5$. The model did not choose to allocate any F-5 aircraft in phase 1, instead attacking all the targets with AIRCRAFT-1As and F-4s in the first phase.

The model exhausted all the aircraft types for the entire conflict. However, given the higher attrition rate in this scenario, insufficient aircraft were available to strike all the intended targets. In phase 1, the model calculated losses of 16.70 AIRCRAFT-1As and 18.50 F-4s. The summary of the numerical results for this initial run of scenario 2 is presented Table 7 and Table 8. The target destruction levels can be found in Table 23 in Appendix F.

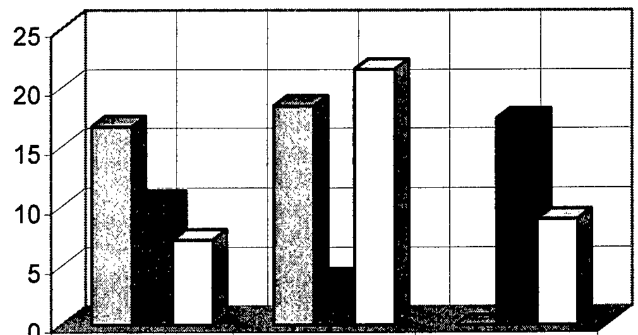
**Table 7. Aircraft-Weapon Allocations for the Second Scenario**

| Aircraft | Total Usage | Total Attr. | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50.00 | 34.35 | 506.53 | NONE | 241.20 | 2766.83 |
| **F-4** | 50.00 | 43.98 | 815.60 | 4199.60 | 364.37 | NONE |
| **F-5** | 50.00 | 26.30 | 621.35 | 579.78 | NONE | NONE |
| **TOTAL** | | 104.63 | 1943.48 | 4779.38 | 605.57 | 2766.83 |

The required number of aircraft for the conflict is increased due to high attrition rate. The model requires more aircraft to produce the required sorties by the targets. As

the attrition rates go up, the model exhausted more of Durandal and Maverick sorties since they have relatively high yields and low attrition rates.

**Table 8. Aircraft Attrition in Each Phase for the Second Scenario**




| | A/C-1 | F-4 | F-5 |
|---|---|---|---|
| 1st Phase | 16.7 | 18.45 | 0 |
| 2nd Phase | 10.44 | 3.91 | 17.36 |
| 3rd Phase | 7.2 | 21.6 | 8.93 |

The marginal values of the aircraft type constraints are 666.51, 623.21 and 629.44 for AIRCRAFT-1A, F-4 and F-5 aircraft respectively. The most contribution can be gained from adding AIRCRAFT-1A aircraft relative to the other two aircraft types. One might think of buying the aircraft type with the highest marginal value to destroy the targets. Unfortunately, the decision to acquire more weapons systems requires the complete examination of buying the most effective aircraft with a high cost *i.e.* AIRCRAFT-1A aircraft vs. buying a slightly less effective aircraft but with a considerably lower cost, i.e. F-4 aircraft. There exists a trade-off between the effectiveness and the cost of that effectiveness.

A review of specific target destruction indicates some of the targets are destroyed while others have not been attacked at all. Only 27.73 targets in target group T-15 were destroyed in phase 2 while phase 2 targets T-3, T-11 and T-14 were not attacked at all. The total target destruction rate across all targets and all phases was 88.1093%. Table 23 in Appendix F indicates the specific target destruction rates for the configuration on the bad weather with no of air supremacy.

Not all the target values destroyed is due to the sortie rates of the available aircraft. The model was not constrained by the munitions in the scenario. The allocated number of aircraft is incapable of producing enough sorties, which are required by the targets with the current sortie rates. It should be noted that the sortie rate is insufficient in this aggregated model. The model does provide, however, specific information in which targets have been struck. This would allow senior leadership to decide if this level of destruction were sufficient or if addition weapon systems should be considered.

If additional aircraft are required, there are two options for producing enough sorties to destroy all the targets, assuming attrition rates remain the same for these conditions. First, increase sortie rates with better maintenance. Second, increase the total number of allocated aircraft either by re-allocation between Tactical Force Commands or with new purchases. Be aware that increasing the sortie rate is not an easy or a quick task.

When the sortie rates are fixed to 3 per day for each aircraft type, the objective function value is increased to 176812.38. The total target destruction rate increase to 90.34% from 88.10% with $SR_{A/C-1} = 3$, $SR_{F-4} = 2.5$ and $SR_{F-5} = 1.5$in the BAD weather with NO air supremacy scenario. Not surprisingly, the contribution of increased sortie

rates is not so significant since F-5 aircraft cannot attack some of the targets according to the target allocation plan. Because of this, increasing F-5 sortie rates did not greatly affect the overall target destruction rate in this particular scenario. On the other hand, with a different target list this change may cause dramatic increase in target destruction rate.

Unless the sortie rate can be significantly increased above 3 per aircraft type per day, the decision-makers know that they will need additional aircraft if they wish to destroy all the projected targets under the poor condition of bad weather and lack of air supremacy.

**4.4. Analysis of Re-allocation**

The affect of re-allocating aircraft resource is investigated in this scenario. The decision-makers have an option of re-allocating AIRCRAFT-1A/D and F-4 aircraft from the other Tactical Command. The entire F-5 squadrons of the nation are already assigned to this conflict.

The total number of allocated aircraft for any particular conflict situation is usually less than the entire air force since some aircraft are reserved for the defense of the rest of the country. For this illustrative scenario, it was determined that 15 more AIRCRAFT-1A and 25 more F-4 aircraft can be re-allocated to this particular conflict. The effects of such a reallocation are investigated over all campaign goals.

Table 9 indicates the percentage of targets which can be destroyed by the addition of up to 15 AIRCRAFT-1A. Adding 15 AIRCRAFT-1A, to a total force of 65, all the other functions held constant, would result in 93.33% of the total targets destroyed. The

study also shows that if the decision-makers want all of the targets to be attacked with only the addition of AIRCRAFT-1As, then the total number of required aircraft is 88 AIRCRAFT-1As plus the initial allocation of 50 F-4s and 50 F-5s. Thirty-eight additional AIRCRAFT-1As would be required, if only AIRCRAFT-1As were purchased or reallocated.

**Table 9. Target Kill Rates for AIRCRAFT-1A Aircraft**

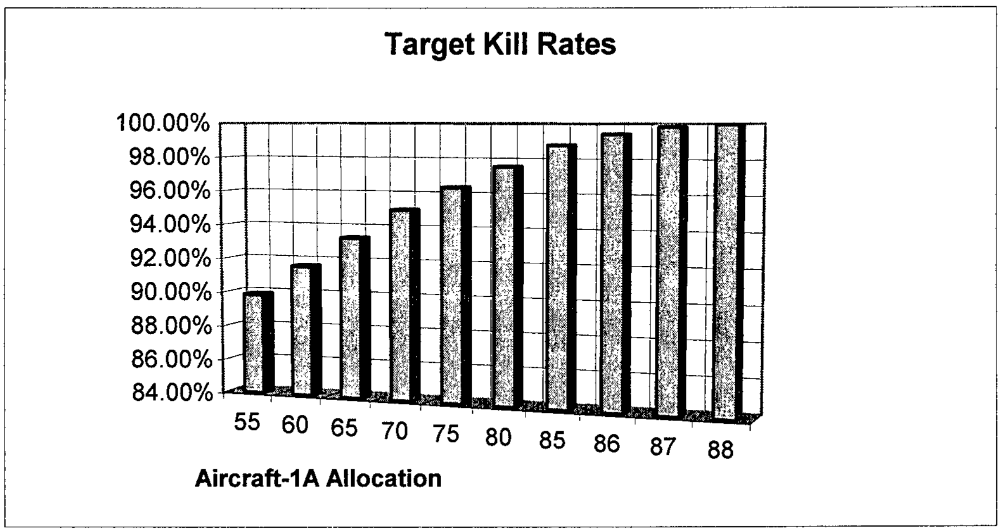



Table 10 investigates adding only F-4s to the currently available aircraft. The total number of F-4s required to kill all the targets is 86; thirty-six additional aircraft are required. That is, the addition of 25 F-4 aircraft will not be enough to kill all the targets. Since neither of the aircraft types is capable of accomplishing the campaign goals alone, the third option will be tested: allocating a mix of AIRCRAFT-1A and F-4 aircraft.

**Table 10. Target Kill Rates for F-4 Aircraft**

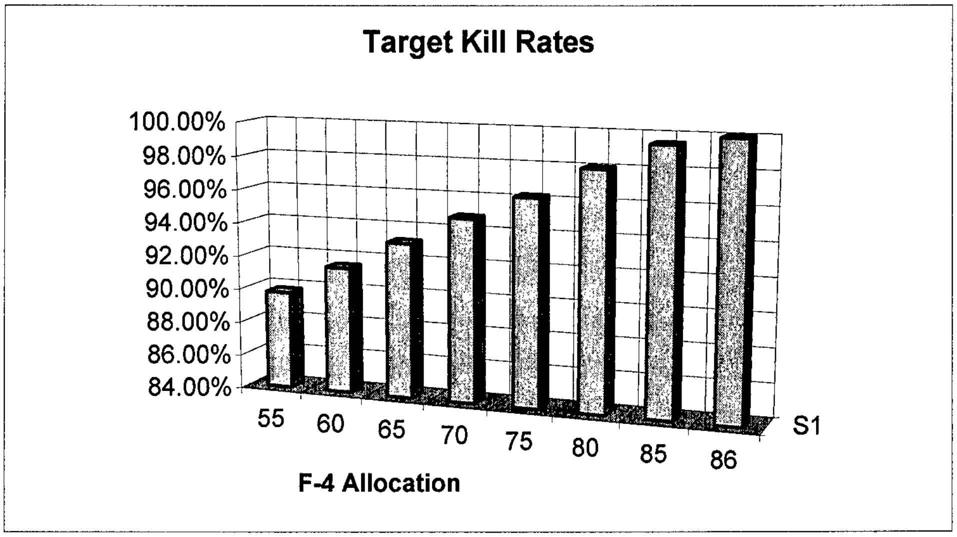



**Table 11. Target Kill Rates for Mix of AIRCRAFT-1A and F-4 Aircraft**

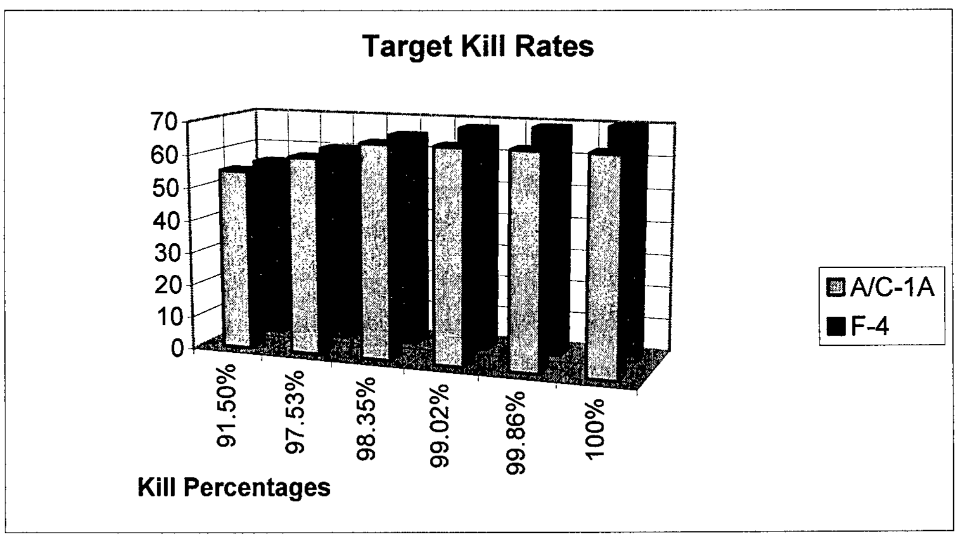



Table 11 shows the results of this allocation. This option has many benefits. The success or the failure of the conflict will belong to the entire air force, since all types of aircraft are involved in the conflict. On the other hand, all pilots will find an opportunity

of having “stick-time” by flying in the real combat environment rather than giving that experience only to the AIRCRAFT-1A or only to the F-4 pilots. It was assumed that the decision-makers want to use all the additional AIRCRAFT-1A aircraft, the study examined target destruction rate according to increase in the AIRCRAFT-1A aircraft level. After allocating an extra 15 AIRCRAFT-1A aircraft, the scenario requires 20 additional F-4 aircraft to accomplish the decision-makers campaign goals. This re-allocation requirement can be satisfied with the current additional aircraft. While not produced here, the model also calculated specific attrition rates of target destruction values for the decision-makers’ review. Such factors are key in deciding adequate force structuring.

### 4.5. The Addition of Aircraft Cost into the Model

In the next model variation, the cost of purchasing an aircraft is included into the model. The new model is tested for the second scenario since this scenario requires additional aircraft from its initial conditions. It is assumed that there is no option to buy additional aircraft during the conflict. That is, all the procurement decisions must be made before the beginning of the conflict. To determine how many aircraft are required to be purchased to destroy all the targets under the poor conditions of scenario 2, the $BUY_a$ variable is added. The aircraft constraint for the first phase is modified as follows:

$$\sum_{m}\sum_{k}\sum_{t=1}\left(X_{amkt}/TS_{amkt}\right)HAK_{amkt} \leq TOTAC_a + BUY_a \quad \text{for all } a.$$

The total number of aircraft for the first phase of the conflict is equal to the current amount of aircraft allocated for the conflict plus any aircraft purchased before the beginning of that conflict. This constraint buys enough aircraft to destroy the designated targets considering required number of aircraft for the second and third phases as well. The other embellishment to the base model is the inclusion of the aircraft costs to the model since each procurement decision requires the use of allocated budget. With the inclusion of a budget constraint, the model is expected to choose the most cost-effective aircraft type. That is, the model balances aircraft cost against increase of Total Target Value Destroyed. The new constraint will be:

$$ACCOST_a BUY_a \leq BUDGET$$

where:

| | |
|---|---|
| $ACCOST_a$ | is the procurement cost of each aircraft type |
| $BUY_a$ | is the number of aircraft of each type needed to be purchased |
| $BUDGET$ | is the total amount of money allocated for aircraft purchases |

For demonstration purposes, the costs of aircraft are assumed 30 units and 10 units for AIRCRAFT-1A/D and F-4 aircraft, respectively. The total allocated budget is 800 units. Since the F-5 is no longer produced, this aircraft was not considered for purchase. The numerical results are summarized at Table 12 and Table 13.

**Table 12. Aircraft-Weapon Allocations for the Budget**

| Aircraft | Total Usage | Total Attr. | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **F-16** | 50 | 32.78 | 506.53 | NONE | 241.20 | 2102.67 |
| **F-4** | 50+80 | 92.63 | NONE | 1215.67 | 821.17 | 2177.08 |
| **F-5** | 50 | 33.93 | 175.39 | 867.48 | NONE | NONE |

**Table 13. Aircraft Attrition for the Budget**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 6.98 | 11.49 | 14.30 | 32.78 |
| **F-4** | 36.06 | 34.59 | 21.98 | 92.63 |
| **F-5** | 15.43 | 12.24 | 6.25 | 33.93 |
| **TOTAL** | 58.48 | 58.33 | 42.54 | 159.37 |

Under the SECOND scenario conditions, with the possibility of purchasing additional aircraft, the model used all allocated Durandal and Maverick weapons. For this scenario, the model destroyed all the targets by purchasing 80 F-4 aircraft. The number of attrited F-4 aircraft is quite high; almost three times those of AIRCRAFT-1As. The total number of sorties flown is increased from 1177.80 to 1225.52 since the number of allocated aircraft resource is increased due to aircraft purchase.

Based solely on the numerical values used in the notional example the decision to buy F-4s is not surprising since there is a ratio of 1:3 between the costs of two aircraft. That is, for the price of a single AIRCRAFT-1A, one can buy three F-4 aircraft. On the other hand, the yields of AIRCRAFT-1A sorties are only slightly higher than F-4 sorties; with no significant difference for some sortie types. In this case, the model prefers to buy a slightly less effective but definitely less expensive aircraft, the F-4. It should be noted,

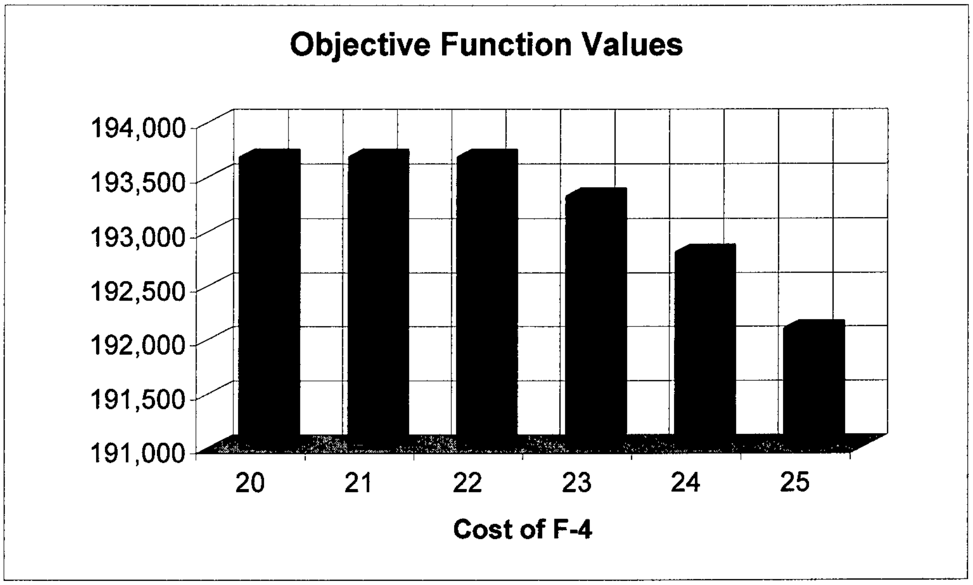
however, this particular scenario does not consider any force modernization consideration. These could be included as additional variable and/or constant, if desired. The sortie allocations can be found in Appendix E.

### 4.6. The Examination of Different Cost Levels for F-4 Aircraft

In this scenario, the overall cost of buying F-4 aircraft is assumed to be higher than its selling price because additional F-4 aircraft are assumed to require modifications. In the current situation, only two main jet bases are capable of handling and servicing F-4s. It is assumed that additional F-4s require modification of other bases. In addition, F-4s avionics and fire control systems need to be modified to meet the expectations of high-tech air campaign theater; *i.e.* on-board Identification-Friend-or-Foe (IFF) interrogators or smart bomb delivery systems, and so forth. When all the factors affecting the cost of F-4s are combined together, it is assumed that new cost for F-4 aircraft will be between 20 units and 25 units.

An analysis of these conditions in Table 14 shows that there is a downward trend in the objective function value as the cost of F-4 aircraft is increased. That is, the model cannot destroy all of the targets with a given budget and cost of aircraft. In other words, the decision-makers can buy enough aircraft to destroy the designated targets as long as the cost of F-4 aircraft stays at or below the 22 units, assuming the cost of AIRCRAFT-1A aircraft and the allocated budget level remain the same. The analysis showed that if the cost of F-4 aircraft goes above 22 units, the model cannot destroy all the planned targets due to insufficient aircraft.

**Table 14. Cost of F-4 is between 20 units and 25 units**




This result is not surprising, since it was calculated that the required number of additional F-4 aircraft is 36 when the number of AIRCRAFT-1A aircraft is fixed to 50. The result shows that the model could buy only 34.78 F-4 aircraft, which is below the required amount of 36, when the cost of F-4 is 23 units. The model did not choose to buy any of the AIRCRAFT-1As during these runs since the model calculates that the F-4s are still much more affective up to cost of 25 units when compared with AIRCRAFT-1A.

The SECOND scenario was run for each cost level where the cost of buying an AIRCRAFT-1A aircraft is fixed to 30 and total budget is 800 units. The all sortie allocations for each cost level can be found in Appendix E.

### 4.6.1 F-4 cost of 20 units

In this scenario, the model destroyed all the targets by buying 40 F-4 aircraft. None of the F-5 aircraft were assigned in the first phase; instead all the targets are

attacked by AIRCRAFT-1A and F-4 aircraft. The numerical results are presented in Table 15 and Table 16. The sortie allocations are presented in Appendix E.

**Table 15. Aircraft-Weapon Allocations where cost of F-4 is 20 units**

| Aircraft | Total Usage | Total Attr. | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 33.60 | 506.53 | NONE | 241.20 | 2450.08 |
| **F-4** | 50+40 | 67.53 | 3710.36 | 3357.20 | 454.02 | 762.36 |
| **F-5** | 50 | 23.78 | 533.84 | 536.26 | NONE | NONE |
| **TOTAL** | | 124.92 | 4750.74 | 3893.47 | 695.22 | 3212.44 |

The model used Mk-82s, Mk-84s and Mavericks at a high level. Durandal usage was not as high for all the cost levels since they can only be used against enemy runways. Due to high attrition rate, the model attrited 124.92 aircraft from a total allocated aircraft amount is 190 for this particular conflict.

**Table 16. Aircraft Attrition where cost of F-4 is 20 units**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 11.49 | 8.39 | 33.60 |
| **F-4** | 21.64 | 16.24 | 29.64 | 67.53 |
| **F-5** | NONE | 20.00 | 3.77 | 23.78 |
| **TOTAL** | 35.36 | 47.75 | 41.81 | 124.92 |

When compared with the total attrition of 159.35 of the previous scenario where the cost of F-4 is 10 units and aircraft purchase is 80 F-4s, this time the model attrited only 124.92 aircraft with the purchase of 40 F-4 aircraft. The model did not allocate any F-5 aircraft in the first phase.

### 4.6.2 F-4 cost of 21 units

If the cost of F-4 aircraft is 21 units, the model purchased .34 AIRCRAFT-1A and 37.60 F-4 aircraft to kill all the targets. The model assigned 31.46 AIRCRAFT-1As and 10.33 F-4s in the first phase but did not assign any F-5 aircraft. Attrition for this run 122.70, slightly lower than the previous run 124.92.

The weapon allocation of the model chose to use all weapons types to kill the targets to accomplish the campaign goals. The purchase of AIRCRAFT-1A aircraft is not material since the weapons inventory level does not limit the model's sortie allocations. That is, the model has many different sortie choices to strike a particular target. The aircraft-weapon allocation and aircraft attrition data can be found in Table 35 and Table 36 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.6.3 F-4 cost of 22 units

In this scenario the model purchased only 36.36 F-4 aircraft to destroy all the targets. The model assigned 31.80 AIRCRAFT-1As and 11.57 F-4s in the first phase but did not assign any F-5 aircraft. Attrition of this run 120.67 is slightly lower than the previous run 122.73. The aircraft-weapon allocation and aircraft attrition data can be found in Table 37 and Table 38 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.6.4 F-4 cost of 23 units

In this state, the model could not accomplish the campaign goal. 3.54 target were not struck in target group T-3. The objective function value is 193,325.94. The model

purchased only 34.78 F-4 aircraft. The over all attrition is 33.42 AIRCRAFT-1A, 64.32 F-4 and 21.88 F-5 aircraft. Attrition on this run of 119.62 is slightly lower than the previous run 120.67. The aircraft-weapon allocation and aircraft attrition data can be found in Table 39 and Table 40 in Appendix G respectively. The target kill levels can be found in Table 24 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.6.5 F-4 cost of 24 units

In this variation, the model could not kill 8.71 targets in target group T-3. The objective function value is 192808.33 and model purchased only 33.33 F-4 aircraft. The overall attrition is 34.17 AIRCRAFT-1A, 63.05 F-4 and 21.88 F-5 aircraft. Again, F-5s were not assigned in phase 1. Attrition for this run of 119.11 is slightly lower than the previous run 119.62. The aircraft-weapon allocation and aircraft attrition data can be found in Table 41 and Table 42 in Appendix G respectively. The target kill levels can be found in Table 25 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.6.6 F-4 cost of 25 units

For this condition, the model could not accomplish the campaign goal, since the model could not destroy any of the targets in target group T-3 in phase 2. The objective function value is 192102.40 and model purchased only 32 F-4 aircraft. The overall attrition is 34.30 F16, 62.30 F-4 and 21.88 F-5 aircraft. The model did not attack target T-3 in phase 2 and partially destroyed target groups T-14 and T-15 in the same phase. Attrition of this run 118.49 is slightly lower than the previous run 119.62. The model used all available Mk-82s, Mk-84s and Mavericks at a significant level. The aircraft-

weapon allocation and aircraft attrition data can be found in Table 43 and Table 44 in Appendix G respectively. The target kill levels can be found in Table 26 in Appendix F.

This analysis demonstrates how various configurations can be tested to provide insight for the decision makers.

### 4.7. The Evaluation of Three Different Modernization Projects

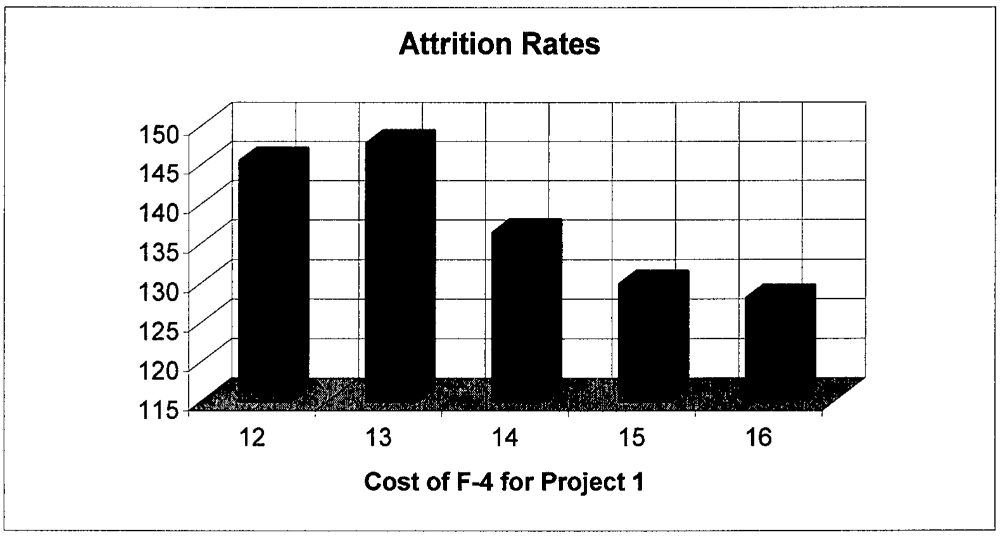
It was determined that all the designated targets can be destroyed as long as the cost of F-4 aircraft could be kept lower than 23 units where the cost of AIRCRAFT-1A is 30 units and the total allocated budget level is 800 units. On the other hand, the decision-makers are given three options for both the modernization of F-4 aircraft and the renovation of main jet bases since these modernization and renovation efforts can be performed at different levels.

In project 1, the decision-makers consider only the renovation of three main jet bases plus the retrofit of self-defense equipments with the approximate cost range of 12 units to 16 units. The second project includes the renovation of all the bases plus the retrofit of self-defense equipments with the approximate cost range of 18 units to 21 units. The third project includes the renovation of all the bases plus the retrofit of both self-defense equipments and replacement of old fire control systems with the new high-tech fire control systems, which has the approximate cost range of 27 units to 33 units.

The over all analysis of the cost range of 12 units and 16 units shows that there is a tendency for decrease in the total number of attrited aircraft as the cost of F-4 aircraft increases. This is because the model chooses the most affective aircraft-munitions combinations to destroy the targets as the cost of killing a target increases in terms of

aircraft cost. In addition, simply having less aircraft contributes to lower attrition rates. An examination of sortie allocations shows that the model has different allocations for each target for each cost level. In other words, as the price of F-4 aircraft increases the model changes the sortie types, away from these that are no longer cost-effective.

**Table 17. Total Aircraft Attrition for Project 1**




### 4.7.1 Project 1, cost of F-4 = 12units

The model purchased 0.96 AIRCRAFT-1A and 64.25 F-4 aircraft to destroy all the targets. The model used all three types of aircraft for the entire conflict and calculated that 26.22 additional F-4 aircraft is required for the first phase. The total attrition by aircraft types is 33.78 AIRCRAFT-1As, 84.44 F-4s and 27.20 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 45 and Table 46 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.2 Project 1, cost of F-4 = 13 units

The model purchased only 61.53 F-4 aircraft to destroy all the targets. The model did not assign any F-5 aircraft in the first phase. In the first phase all the targets are attacked by AIRCRAFT-1As and F-4s in the first phase where additional aircraft are required for the second and third phases. The total attrition by aircraft types is 33.46 AIRCRAFT-1As, 91.95 F-4s and 22.28 F-5s. In this run, total attrition is higher than in previous cases. The main reason for this is that the model chose to fly more Mk-82 sorties, which has relatively high attrition for F-4 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 47 and Table 48 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.3 Project 1, cost of F-4 = 14 units

The model purchased 0.81 AIRCRAFT-1A and 55.40 F-4 aircraft to destroy all the targets. The model did not assign any F-5 aircraft in the first phase; instead all the targets are attacked by AIRCRAFT-1As and F-4s. The total attrition by aircraft types is 33.75 AIRCRAFT-1As, 77.36 F-4s and 25.19 F-5s.

The total attrition is relatively less than the previous run since the model exhausted more smart bombs, which have lower attrition rates to strike the targets. The aircraft-weapon allocation and aircraft attrition data can be found in Table 49 and Table 50 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.4 Project 1, cost of F-4 = 15 units

The model purchased only 3.46 AIRCRAFT-1A and 46.39 F-4 aircraft to destroy all the targets when the cost of F-4 is 15 units per aircraft. The model did not initially assign any F-5 aircraft. Instead all the targets are initially attacked by AIRCRAFT-1As and F-4s, where an additional 15.30 F-4 aircraft are required in the first phase. The total attrition by aircraft types is 36.46 AIRCRAFT-1As, 66.63 F-4s and 26.68 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 51and Table 52 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.5 Project 1, cost of F-4 = 16 units

With a price of 16 units per F-4's, the model purchased 3.47 AIRCRAFT-1A and 43.50 F-4 aircraft to destroy all the targets. The model did not assign any F-5 aircraft in phase 1. Initially all the targets are attacked by AIRCRAFT-1As and F-4s where an additional 12.40 F-4 aircraft are required in the first phase. The total attrition by aircraft types is 36.46 AIRCRAFT-1As, 64.83 F-4s and 26.68 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 53 and Table 54 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.6 Project 2, cost of F-4 = 18 units

The over all analysis of the second project shows that, the total number of aircraft losses decreases as the cost of F-4 aircraft increases. This is because the model buys less aircraft. Although the model buys less aircraft, all planned targets are destroyed with a

total target destruction rate of 100%. With the cost of F-4 aircraft below 23 units, the model can still buy enough F-4 aircraft to destroy all the planned targets.

The model purchased only 44.44 F-4 aircraft to destroy all the targets when F-4s cost 18 units per aircraft. The model again did not assign any F-5 aircraft in the first phase. No additional aircraft were required in the first phase. The total attrition by aircraft types is 33.86 AIRCRAFT-1As, 67.40 F-4s and 26.79 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 55 and Table 56 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.7 Project 2, cost of F-4 is 19 units

The model purchased .30 AIRCRAFT-1A and 41.62 F-4 aircraft to destroy all the targets. In phase 1 all the targets are attacked by AIRCRAFT-1As and F-4s, where 1.41 additional F-4 aircraft are required. The total attrition by aircraft types is 33.29 AIRCRAFT-1As, 64.95 F-4s and 26.68 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 57 and Table 58 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.8 Project 2, cost of F-4 = 20 units

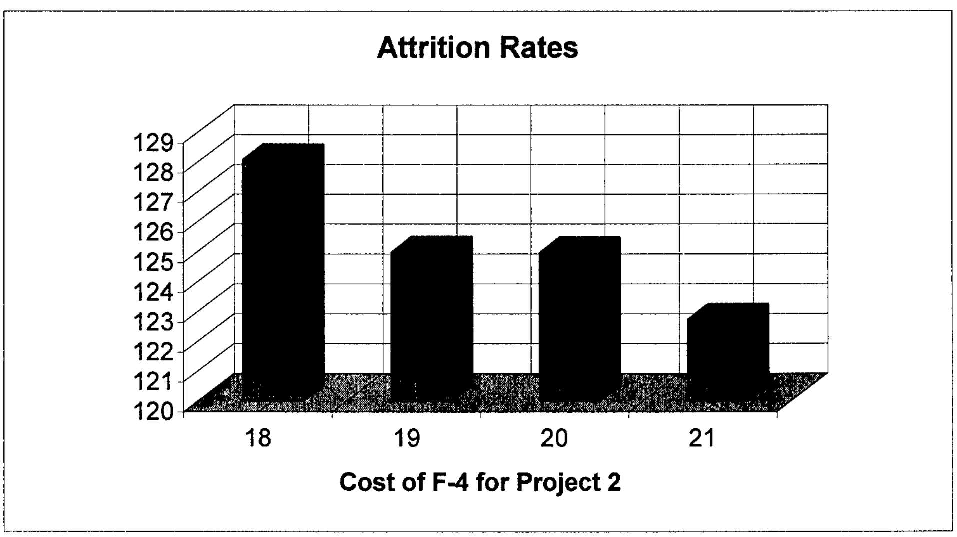
The model purchased only 40 F-4 aircraft to destroy all the targets when the price was 20 units per F-4. In phase 1 all the targets are attacked by AIRCRAFT-1As and F-4s where there is no additional aircraft required in the first phase. The total attrition by aircraft types is 33.60 AIRCRAFT-1As, 67.53 F-4s and 23.78 F-5s. The aircraft-weapon

allocation and aircraft attrition data can be found in Table 59 and Table 60 in Appendix G respectively. The sortie allocations are presented in Appendix E.

### 4.7.9 Project 2, cost of F-4 = 21 units

The model purchased 0.34 AIRCRAFT-1A and 37.60 F-4 aircraft to destroy all the targets. The model attacked all targets in phase 1 with AIRCRAFT-1As and F-4s. No additional aircraft were required in the first phase. The total attrition by aircraft types is 33.30 AIRCRAFT-1As, 67.52 F-4s and 21.88 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 61 and Table 62 in Appendix G respectively. The sortie allocations are presented in Appendix E.

**Table 18. Total Aircraft Attrition for Project 2**

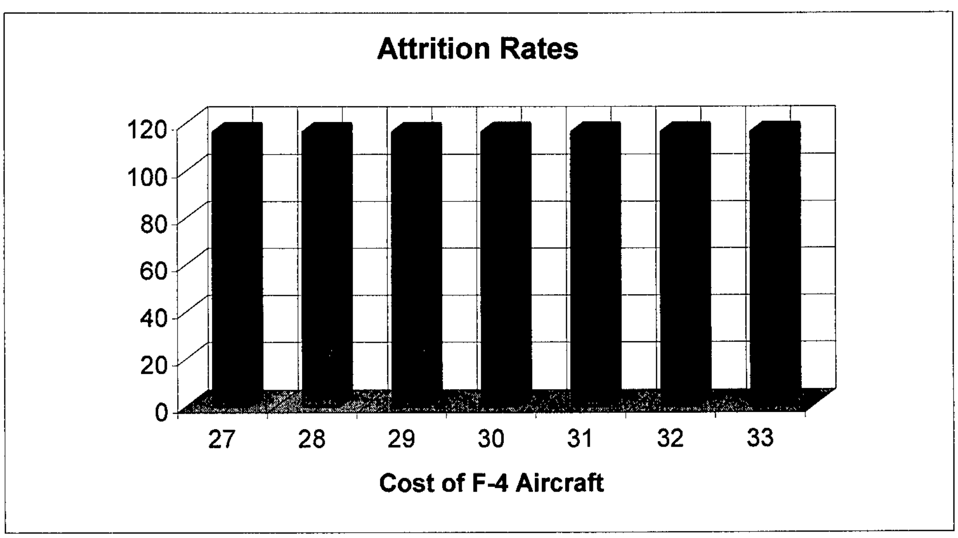


#### 4.7.10 Project 3, cost of F-4 = 27 units

In this scenario, the model could not kill any of the targets in target group T-3 and target groups T-14 and T-15 are partially killed in phase 2. The objective function value is 190735.95 and model purchased only 29.62 F-4 aircraft. The over all attrition is 34.30 AIRCRAFT-1A, 61.15 F-4 and 21.88 F-5 aircraft.

The over all evaluation of the third project in Table 19 shows that even though the attrition rates are almost the same for each cost level, the sortie allocations are quite different for certain types of targets. For instance, the model assigns 27.48 sortie of AIRCRAFT-1A and 78.62 sortie of F-4 aircraft loaded with Mavericks against target group T-15 in phase 3 where it assigns only 77.83 sortie of AIRCRAFT-1A, loaded with Mavericks against the same target in the same phase for the cost levels of 27 and 28 respectively.

**Table 19. Total Aircraft Attrition for Project 3**



Since the cost of F-4 aircraft is above 23 units, it is already known that aircraft purchases will not be enough to accomplish the campaign goals. The over all analysis of project 3, which includes the renovation of all the bases and modernization of the self-defense equipments and fire control systems of F-4 aircraft, shows that this is not a good option to choose if the decision makers' only concern is to destroy all the planned targets given the cost and budget levels allocated to this conflict. The aircraft-weapon allocation and aircraft attrition data can be found in Table 63 and Table 64 in Appendix G respectively. The target destruction levels can be found in Table 27 in Appendix F.

This type of different sortie allocations for the same target group is performed at each cost level by the model. The model considers many sortie allocation options for each target group. This feature could, of course, be added. The model exhausts varying amount of weapons for each cost levels as well. For instance, for the cost levels of 27 units and 28 units, the models uses more of each Mk-82s and Mk-84s but when the cost level is at or above 29 units the model exhausts more Mavericks relative to Mk-82s and Mk-84s.

### 4.7.11 Project 3, cost of F-4 = 28 units

In this case, the model could not accomplish the campaign goal. Again the model could not destroy any of the targets in target group T-3 and target groups T-14 and T-15 are partially killed in phase 2. The objective function value is 190161.50 and model purchased 6.64 AIRCRAFT-1As and 21.44 F-4 aircraft. The over all attrition is 40.85 AIRCRAFT-1As, 54.37 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 65and Table 66 in Appendix G respectively.

The target destruction levels can be found in Table 28 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.7.12 Project 3, cost of F-4 = 29 units

For this case, the model again could not accomplish the campaign goal. There was insufficient resource to strike any of the targets in target group T-3 and target groups T-14 and T-15 are partially killed in phase 2. The objective function value is 189861.86 and model purchased 16.72 AIRCRAFT-1As and 10.28 F-4 aircraft. The over all attrition is 50.74 AIRCRAFT-1A, 44.41 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 67 and Table 68 in Appendix G respectively. The target destruction levels can be found in Table 29 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.7.13 Project 3, cost of F-4 = 30 units

With F-4s costing 30 units per aircraft, the model could not accomplish the campaign goal; again there was insufficient aircraft to strike any one of the targets in target group T-3; target groups T-14 and T-15 are partially killed in phase 2. The objective function value is 189664.14 and model purchased 16.72 AIRCRAFT-1As and 9.94 F-4 aircraft. The over all attrition is 50.74 AIRCRAFT-1A, 44.24 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 69 and Table 70 in Appendix G respectively. The target destruction levels can be found in Table 30 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.7.14 Project 3, cost of F-4 = 31 units

Again, the model could not accomplish the campaign goal. Target group T-3 and target groups T-14 and T-15 are partially destroyed in phase 2. The objective function value is 189479.18 and model purchased 16.72 AIRCRAFT-1As and 9.62 F-4 aircraft. The over all attrition is 50.74 AIRCRAFT-1A, 44.09 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 71 and Table 72 in Appendix G respectively. The target destruction levels can be found in Table 31 in Appendix F.

### 4.7.15 Project 3, cost of F-4 = 32 units

At 32 units per F-4, there are insufficient aircraft to meet the campaign goal. The air force is again unable to destroy any of the targets in target group T-3 and target groups T-14 and T-15 are partially killed in phase 2. The objective function value is 189305.79 and model purchased 16.72 AIRCRAFT-1As and 9.32 F-4 aircraft. The over all attrition is 50.74 AIRCRAFT-1A, 43.94 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 73 and Table 74 in Appendix G respectively. The target destruction levels can be found in Table 32 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.7.16 Project 3, cost of F-4 = 33 units

In this case, F-4s costing 33 units per aircraft the model could not accomplish the campaign goal. There are insufficient platforms to destroy any one of the targets in target group T-3 and target groups T-14 and T-15 are partially killed in phase 2. The objective function value is 189154.47 and model purchased 25.01 AIRCRAFT-1As and 1.49 F-4.

The over all attrition is 58.79 AIRCRAFT-1A, 36.80 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 75 and Table 76 in Appendix F respectively. The target destruction levels can be found in Table 33 in Appendix F. The sortie allocations are presented in Appendix E.

### 4.8 Results of the SECOND Allocation Plan

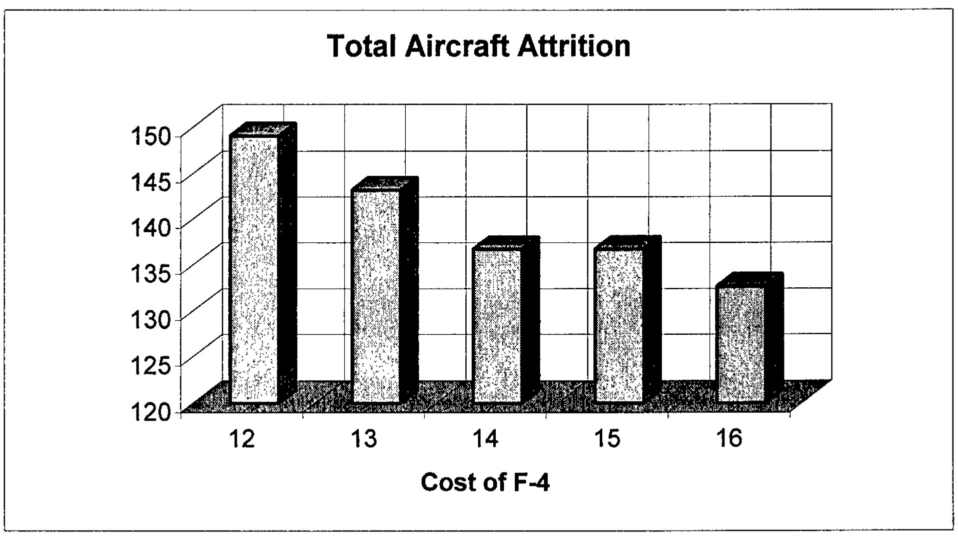
In this part of the study, the second allocation plan, which includes the allocation of AIRCRAFT-1D, will be tested for BAD weather and NO AIR SUPREMACY condition to compare with the results of the first allocation plan where AIRCRAFT-1As were used. The model could not destroy any of the targets in target group T-3 and T-14 while target groups T-11, T-12 and T-15 are only partially destroyed. The objective function value is 179642.25, which is 7055.22 greater than the first allocation. The target destruction rate is 91.91% versus 88.10% for the first allocation plan. The model did not choose to allocate any F-5 aircraft in phase 1, instead all the targets were attacked by AIRCRAFT-1Ds and F-4s. The model exhausted all the aircraft types for the entire conflict. The total attrited number of aircraft is 2.27 less than the first allocation plan. In phase 1 model incurs the loss of 16.18 AIRCRAFT-1Ds and 15.39 F-4s.

This analysis now allows the decision-makers insight that if they choose to allocate AIRCRAFT-1Ds they can destroy more targets and loose less aircraft. Analysis of the model output shows that the model chooses different sortie types, which are much affective to kill the same target on cost of aircraft. The numerical results are presented in Table 77 and Table 78 in Appendix G.

## 4.9 SECOND Allocation Plan for the first project

In this section, the second allocation plan is tested for the first project that the decision-makers proposed. The table below shows that as the cost of F-4 aircraft is increased the total number of lost aircraft is decreased. On the other hand, there is no difference between AIRCRAFT-1A and AIRCRAFT-1D in terms of the total target destruction rate since both types of aircraft destroyed all the planned targets for the given cost range and budget level.

**Table 20. Total Aircraft Attrition for the F-4 Aircraft**




### 4.9.1 The cost of F-4 = 12 units

The model purchased additional 66.66 F-4 aircraft to destroy all the targets. The model assigned all three types of aircraft and calculated that 19.05 additional F-4 aircraft is required for the first phase of the conflict. The total attrition by aircraft types is 35.04

AIRCRAFT-1Ds, 83.76 F-4s and 30.26 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 79 and Table 80 in Appendix G respectively.

### 4.9.2 The cost of F-4 = 13 units

The model purchased 0.70 AIRCRAFT-1D and 59.91 F-4 aircraft to destroy all the targets. The model assigned all three types of aircraft and calculated that 12.29 additional F-4 aircraft are required for the first phase of the conflict. The total attrition by aircraft types is 35.90 AIRCRAFT-1Ds, 80.42 F-4s and 26.85 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 81 and Table 82 in Appendix G respectively.

### 4.9.3 The cost of F-4 = 14 units

The model purchased 0.45 AIRCRAFT-1D and 56.17 F-4 aircraft to destroy all the targets. The model assigned all three types of aircraft and calculated that 8.55 additional F-4 aircraft is required for the first phase of the conflict. The total attrition by aircraft types is 35.75 AIRCRAFT-1Ds, 78.56 F-4s and 26.68 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 83 and Table 84 in Appendix G respectively.

### 4.9.4 The cost of F-4 = 15 units

The model purchased 53.33 F-4 aircraft to destroy all the targets. The model assigned all three types of aircraft and calculated that 22.93 additional F-4 aircraft is required for the first phase of the conflict. The total attrition by aircraft types is 36.38

AIRCRAFT-1Ds, 73.46 F-4s and 26.86 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 85 and Table 86 in Appendix G respectively.

### 4.9.5 The cost of F-4 = 16 units

The model purchased 1.25 AIRCRAFT-1D and 47.64 F-4 aircraft to destroy all the targets. The model assigned all three types of aircraft. It is estimated that 22.82 additional F-4 aircraft is required for the first phase of the conflict. The total attrition by aircraft types is 37.78 AIRCRAFT-1Ds, 68.18 F-4s and 26.68 F-5s. The aircraft-weapon allocation and aircraft attrition data can be found in Table 87 and Table 88 in Appendix G respectively.

## 4.10 SECOND Allocation Plan for the Third Project

In this part of the research, the second allocation plan is tested for the third project that the decision-makers proposed. When compared with the first allocation plan, it should be noted that the use of AIRCRAFT-1Ds increases target destruction rate. The first allocation plan never destroyed all the targets for the price range of 27 units and 33 units for the F-4 aircraft and lost more aircraft where AIRCRAFT-1D destroyed all the targets. The allocation of AIRCRAFT-1D can be suggested as a good choice for BAD weather with NO air supremacy condition for the given cost and budget levels to the decision makers.

### 4.10.1 The cost of F-4 = 27 units

In this scenario, the model destroyed all the designated targets and purchased 22.3167 AIRCRAFT-1D and 4.83 F-4 aircraft. In the first allocation plan, the objective

value was 190735.95. The model purchased only 29.62 F-4 aircraft while the over all attrition was 34.30 AIRCRAFT-1A, 61.15 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 89 and Table 90 in Appendix G respectively.

### 4.10.2 The cost of F-4 = 28 units

In this scenario, the model destroyed all the designated targets and purchased 20.62 AIRCRAFT-1D and 6.47 F-4 aircraft. In the first allocation plan, the objective value was 190161.50 and the model purchased 6.64 AIRCRAFT-1D and 21.44 F-4 aircraft with an over all attrition was 40.85 AIRCRAFT-1A, 54.37 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 91 and Table 92 in Appendix G respectively.

### 4.10.3 The cost of F-4 = 29 units

In this scenario, the model destroyed all the designated targets and purchased 19.78 AIRCRAFT-1D and 7.11 F-4 aircraft. In the first allocation plan, the objective value was 189861.86 with a recommended purchase 16.72 AIRCRAFT-1D and 10.28 F-4 aircraft where the over all attrition was 50.74 AIRCRAFT-1A, 44.41 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 93 and Table 94 in Appendix G respectively.

### 4.10.4 The cost of F-4 = 30 units

Under these conditions, the model destroy all the designated targets and purchased 18.76 AIRCRAFT-1D and 7.90 F-4 aircraft. In the first allocation plan, the

objective value was 189664.14 with 16.72 AIRCRAFT-1D and 9.94 F-4 aircraft purchased. The over all attrition was 50.74 AIRCRAFT-1A, 44.24 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 95 and Table 96 in Appendix G respectively.

### 4.10.5 The cost of F-4 = 31 units

With the cost of F-4s equal to 31 units, the model destroyed all the designated targets while purchasing 17.48 AIRCRAFT-1D and 8.88 F-4 aircraft. In the first allocation plan, the objective value was 189479.18 and model purchased 16.72 AIRCRAFT-1D and 9.62 F-4 aircraft where the over all attrition was 50.74 AIRCRAFT-1A, 44.09 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 97 and Table 98 in Appendix G respectively.

### 4.10.6 The cost of F-4 = 32 units

In this scenario, all the designated targets were destroyed. Purchases were 15.83 AIRCRAFT-1D and 10.15 F-4 aircraft. In the first allocation plan, the objective value was 189305.79 with 16.72 AIRCRAFT-1D and 9.32 F-4 aircraft purchased. The over all attrition was 50.74 AIRCRAFT-1A, 43.94 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 99 and Table 100 in Appendix G respectively.

### 4.10.7 The cost of F-4 = 33 units

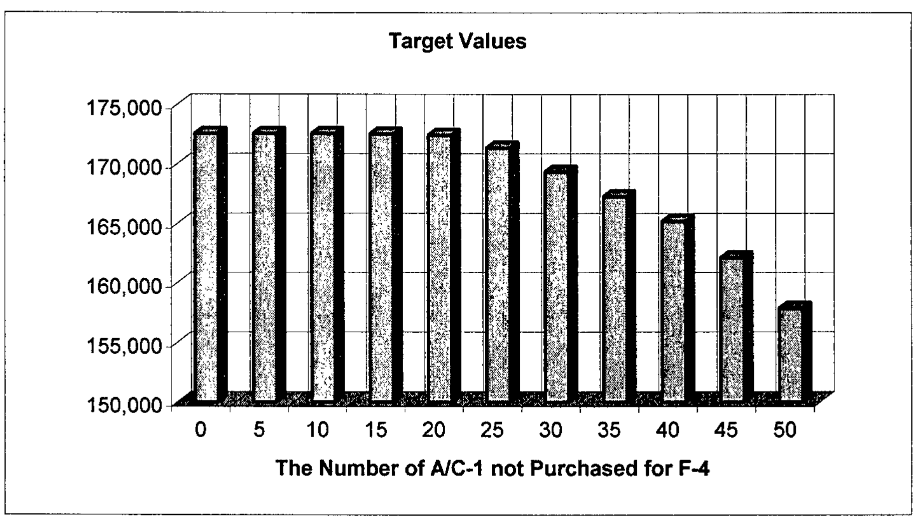
In this scenario, the model destroy all the designated targets and purchased 14.14 AIRCRAFT-1D and 11.38 F-4 aircraft. In the first allocation plan, the objective value

was 189154.47 and the model purchased 25.01 AIRCRAFT-1D and 1.49 F-4 aircraft with an over all attrition of 58.79 F16, 36.79 F-4 and 21.88 F-5 aircraft. The aircraft-weapon allocation and aircraft attrition data can be found in Table 101 and Table 102 in Appendix G respectively.

## 4.11 Parametric Analysis of the Aircraft Cost

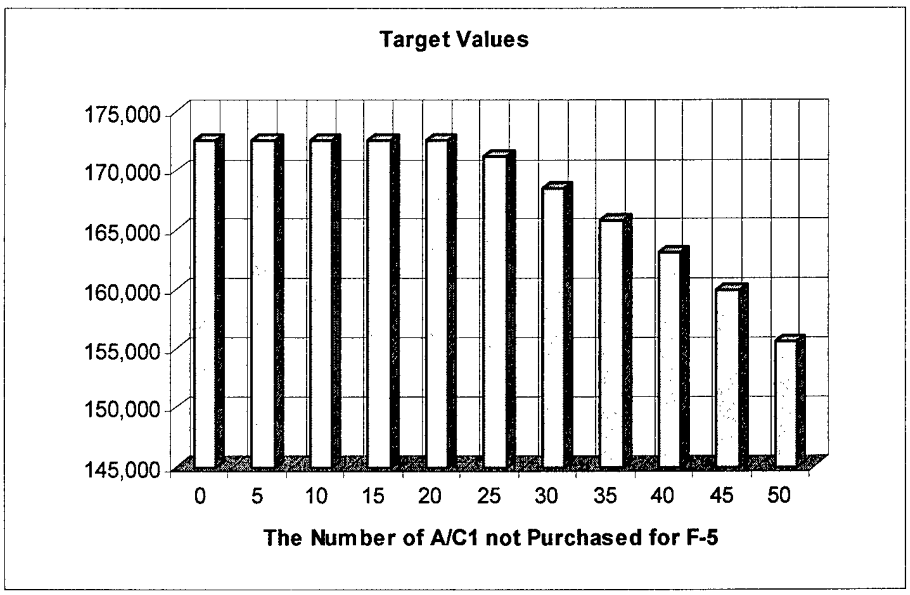
In this part of the analysis, the cost ratio between AIRCRAFT-1A and F-4 was examined. Improvement in the objective function value for buying more of F-4 aircraft instead of buying AIRCRAFT-1A is investigated. Table 21 shows that there was no change in the objective function value until 20 AIRCRAFT-1As were given up to buy 60 more F-4 aircraft since their yield values were very close to each other. On the other hand, if 25 or more AIRCRAFT-1As were given up, there was a decrease in the objective function value for the bad weather with no air supremacy condition. If 50 AIRCRAFT-1As were given up, the objective value accomplished was 157,862.

**Table 21. Tradeoff between AIRCRAFT-1A and F-4**



Another tradeoff analysis had been performed between AIRCRAFT-1A and F-5 aircraft. Instead of buying one AIRCRAFT-1A, one could buy 5 F-5s. Table 21 shows that if 25 or more AIRCRAFT-1As were given up, there was a decrease in objective function value. If 50 AIRCRAFT-1As were given up buy F-5s, the objective function value would be 155,103 since F-5s could not be assigned against all targets.

**Table 22. Tradeoff between AIRCRAFT-1A and F-5**




## 4.12 Summary

This chapter presented the results obtained from the implementations of the proposed model. For the first scenario, the model used all the types of weapon platforms and munitions to destroy all the planned targets. The total number of aircraft losses was low due to low attrition rate. For the second scenario, the model could not destroy all

planned targets since the number of weapon platforms was insufficient. The model required more aircraft to fly the required sorties.

The investigation of reallocating aircraft resource revealed that neither of the aircraft types is capable of accomplishing the campaign goals alone. After allocating an extra 15 AIRCRAFT-1A aircraft, the scenario requires 20 additional F-4 aircraft to accomplish the decision-makers campaign goals. This re-allocation requirement can be satisfied with the current additional aircraft.

When the cost of purchasing an aircraft was included into the model, the model chose the sorties more carefully. The most cost-effective aircraft type, F-4, was chosen to accomplish the campaign goals at a certain cost level. The total number of targets destroyed was decreased as the cost of F-4 increased since the model could not buy enough aircraft to destroy all the planned targets. The allocation of AIRCRAFT-1D was found more effective than the allocation of AIRCRAFT-1A. The use of AIRCRAFT-1D increased target destruction rate and decreased over all attrition. While this analysis was conducted on notional data, it does demonstrate the range of investigations that can be accomplished.

# V. SUMMARY and FUTURE RESEARCH

## 5.1. Summary

The model in this thesis provides a decision support tool that aids decision-makers in determining the "right" mix of weapon platforms and munitions for future force structure composition.

The literature review revealed that a force structure model should cover the duration of the conflict, the cost of buying an aircraft or weapons, and aircraft attrition. The model should also be able to incorporate decision-makers' campaign objectives.

The suggested model divides the entire conflict into phases. Aircraft and munitions requirements can be determined separately for each phase. The use of phases also helps to define separate yield and target values, target numbers, and bomb loads for the conflict. The enemy defense, the number of weapon systems and munitions left, and the tactical importance of some targets may change as the conflict continues.

The model can be used to determine *how many* and *which type* of weapon platforms and munitions should be procured, considering different scenarios and different cost levels of each aircraft type. In the illustrative example, the AIRCRAFT-1 type aircraft is three times more expensive than F-4 aircraft but the yield values of the sortie types flown by these aircraft are very close to each other. For this reason, the model usually prefers to spend the allocated budget for buying more F-4 aircraft. The model can also be used to compare different aircraft types to decide which type is more effective

or causes less attrition. In the example, AIRCRAFT-1Ds destroyed more targets than AIRCRAFT-1As for the bad weather with no air supremacy scenario.

The $HAK_{amkt}$ parameter is used to include decision-makers' campaign goals. Each sortie is classified according to decision-makers' objectives. The $HAK_{amkt}$ parameter can also be used to specify the feasible sortie combinations to include the operational limitations of a nation. For instance, the model does not have an option of assigning sortie combinations of F-5 aircraft, loaded with Durandal, against T-1, in phase 1 since F-5s cannot carry smart bombs.

Since this is an aggregate model, the parameter *SEM* is defined to cover BDA and enemy re-generation capabilities. The parameter *SEM* increases the number of targets in each target group to guarantee complete destruction. The bomb load ($B_{amk}$) is defined according to aircraft type, munitions type and target group. This approach allows partial loads for each sortie type, which adds flexibility into the model.

The model is also capable of determining the total number of aircraft loses by aircraft type in each phase. The total aircraft attrition data can be used to plan the aircraft and munitions requirements for each phase.

## 5.2. Future Research

Since the proposed model was an aggregation, many aspects of the air campaign were not covered in detail including BDA and enemy regeneration capabilities. Some natural extensions to this research would involve the detailed formulations of these variables.

Calculations of $TS_a$ would require the addition of probability to a certain extent since its calculation requires the use of *sortie rate* and sortie rates may change. For instance, it was assumed that the sortie rate of AIRCRAFT-1 is 3. That is, a single AIRCRAFT-1A can produce 3 sorties per day. What happens if attrition is higher than expected? Losses and sortie rates would vary.

The determination of the correct value for the *SEM* parameter requires a complete analysis of all the factors affecting it. In the example, it was assumed that 20% increase in total target number would suffice. Another research area would be the addition of *BUY* variable for the munitions inventory.

The model could also be improved by adding additional objective functions *i.e.* minimizing over all attrition. The same problem could be solved by using Goal Programming approach adopted in CFAM.

The model does, however, provide a number of useful analyses for a moderately-sized nation to construct its force structure.

# APPENDIX A: INVENTORY LEVELS for AIRCRAFT and WEAPONS

| | | |
|---|---|---|
| AIRCRAFT-1A | = | 50 |
| AIRCRAFT-1D | = | 50 |
| F-4 | = | 50 |
| F-5 | = | 50 |
| Mk-82 | = | 10,000 |
| Mk-84 | = | 8,000 |
| Durandal | = | 5,000 |
| Maverick | = | 5,000 |
| Cost of A/C-1A | = | 30 units |
| Cost of A/C-1D | = | 30 units |
| Cost of F-4 | = | 10 units |
| BUDGET | = | 800 units |

# APPENDIX B: BASELINE MODEL

***Indices:***

| | | |
|---|---|---|
| $a$ | aircraft type | AIRCRAFT-1 / F-4 / F-5 |
| $m$ | weapons | Mk-82 / Mk-84 / Durandal / Maverick |
| $k$ | target groups | T-1, T-2,…,T-14, T-15 |
| $t$ | time phases | Phase 1 (P-1): 3 days, Phase 2 (P-2): 7 days, Phase 3 (P-2): 10 days |

***Variables:***

| | |
|---|---|
| $X_{amkt}$ | number of sorties flown by each aircraft type $a$, loaded with munitions$m$, against target $k$, in phase $t$. |
| $YIELD_{amkt}$ | yield (fractional target kills) per sortie, |
| $TVAL_{kt}$ | target value assigned to target $k$, in phase $t$. |
| $HAK_{amkt}$ | a binary parameter which specifies the allowable/feasible sortie types. |
| $SR_a$ | daily sortie rate of a single aircraft type $a$. |
| $SEM$ | a constant (1.2). |
| $EA_{amkt}$ | expected attrition for a single sortie |
| $TS_{amkt}$ | total number of sorties that *can* be produced by a single aircraft type $a$, loaded with munitions $m$, against target $k$, in phase $t$. |
| $NDAYS_t$ | is the duration of that phase. How many days there are in one time phase |
| $ACCOST_a$ | cost of buying an aircraft |
| $BUDGET$ | total amount of budget allocated for aircraft purchases. |
| $TOTAC_a$ | total number of aircraft type $a$. |

$TOTWPN_m$ total number of munitions $m$.

$TOTTGT_{kt}$ total number of targets $k$ in each phase $t$.

***Objective Function:***

$$MaxTVD = \sum_a \sum_m \sum_k \sum_t X_{amkt} YIELD_{amkt} TVAL_{kt} HAK_{amkt}$$

***Constraints:***

$$\sum_a \sum_m \sum_k \sum_{t=1} \{ X_{amkt} / TS_{amkt} \} HAK_{amkt} \le TOTAC_a$$ for each $a$ and $t = 1$

$$\sum_a \sum_m \sum_k \sum_{t \ge 2} \{ X_{amkt} / TS_{amkt} \} HAK_{amkt} \le TOTAC_a - \sum_{t-1} \left[ \sum_{mk} X_{amkt} EA_{amkt} \right]$$

for each $a$ and $t = 2,3$

$$\sum_a \sum_k X_{amkt} B_{amk} HAK_{amkt} \le TOTWPN_m$$ for each $m$ and $t$.

$$\sum_a \sum_m \sum_k \sum_t X_{amkt} YIELD_{amkt} HAK_{amkt} \le TOTTGT_{kt} SEM$$ for each target k.

$$X_{amkt} \ge 0$$

# APPENDIX C: BASELINE MODEL MODIFIED FOR BUDGET

***Objective Function:***

$$MaxTVD = \sum_{a}\sum_{m}\sum_{k}\sum_{t} X_{amkt} YIELD_{amkt} TVAL_{kt} HAK_{amkt}$$

***Constraints:***

$$\sum_{a}\sum_{m}\sum_{k}\sum_{t=1}\{\ {}^{X_{amkt}}\!/\!_{TS_{amkt}}\ \} HAK_{amkt} \leq TOTAC_a + BUY_a$$ for each $a$ and $t = 1$

$$\sum_{a}\sum_{m}\sum_{k}\sum_{t\geq 2}\{\ {}^{X_{amkt}}\!/\!_{TS_{amkt}}\ \} HAK_{amkt} \leq TOTAC_a - \sum_{t-1}\left[\sum_{mk} X_{amkt} EA_{amkt}\right] + BUY_a$$

for each $a$ and $t = 2,3$

$$\sum_{a}\sum_{k} X_{amkt} B_{amk} HAK_{amkt} \leq TOTWPN_m$$ for each $m$ and $t$.

$$\sum_{a}\sum_{m}\sum_{k}\sum_{t} X_{amkt} YIELD_{amkt} HAK_{amkt} \leq TOTTGT_{kt} SEM$$ for each target k.

$$\sum_{a} ACCOST_a BUY_a \leq BUDGET$$ for each $a$.

$$X_{amkt} \geq 0$$

# APPENDIX D: GAMS FORMULAITON OF BASELINE MODEL

$TITLE BASELINE MODEL 1 GOOD WEATHER/ AIR SUPREMACY / LOW ATTRITION
$OFFUPPER

SETS
A aircraft type /AIRCRAFT-1A, F-4, F-5/
M weapon type /MK-82, MK-84, DURA, MAVE/
K targets /T-1,T-2,T-3,T-4,T-5,T-6,T-7,T-8,T-9, T-10, T-11, T-12, T-13, T-14, T-15/
T phases /P-1,P-2,P-3/;

**TABLE YIELD (A,M,K,T) fractional kills per sortie**

| | P-1 | P-2 | P-3 |
|---|---|---|---|
| F-16.MK-82.T-1 | .995 | .995 | .0001 |
| F-16.MK-82.T-2 | .995 | .710 | .412 |
| F-16.MK-82.T-3 | .381 | .285 | .0001 |
| F-16.MK-82.T-4 | .394 | .0001 | .0001 |
| F-16.MK-82.T-5 | .393 | .0001 | .0001 |
| F-16.MK-82.T-6 | .0001 | .205 | .410 |
| F-16.MK-82.T-7 | .0001 | .0001 | .153 |
| F-16.MK-82.T-8 | .0001 | .395 | .204 |
| F-16.MK-82.T-9 | .152 | .0001 | .220 |
| F-16.MK-82.T-10 | .0001 | .325 | .470 |
| F-16.MK-82.T-11 | .415 | .140 | .0001 |
| F-16.MK-82.T-12 | .0001 | .0001 | .395 |
| F-16.MK-82.T-13 | .295 | .420 | .0001 |
| F-16.MK-82.T-14 | .0001 | .444 | .230 |
| F-16.MK-82.T-15 | .0001 | .470 | .115 |
| F-16.MK-84.T-1 | .399 | .408 | .0001 |
| F-16.MK-84.T-2 | .0001 | .0001 | .406 |
| F-16.MK-84.T-3 | .399 | .415 | .0001 |
| F-16.MK-84.T-4 | .411 | .0001 | .0001 |
| F-16.MK-84.T-5 | .416 | .0001 | .0001 |
| F-16.MK-84.T-6 | .0001 | .416 | .421 |
| F-16.MK-84.T-7 | .0001 | .0001 | .412 |
| F-16.MK-84.T-8 | .0001 | .400 | .410 |
| F-16.MK-84.T-9 | .385 | .0001 | .415 |
| F-16.MK-84.T-10 | .0001 | .440 | .495 |
| F-16.MK-84.T-11 | .430 | .455 | .0001 |

| | | | |
|---|---|---|---|
| F-16.MK-84.T-12 | .0001 | .0001 | .525 |
| F-16.MK-84.T-13 | .415 | .444 | .0001 |
| F-16.MK-84.T-14 | .0001 | .311 | .301 |
| F-16.MK-84.T-15 | .0001 | .556 | .482 |
| F-16.DURA.T-1 | .450 | .425 | .0001 |
| F-16.DURA.T-2 | .0001 | .0001 | .0001 |
| F-16.DURA.T-3 | .0001 | .0001 | .0001 |
| F-16.DURA.T-4 | .0001 | .0001 | .0001 |
| F-16.DURA.T-5 | .0001 | .0001 | .0001 |
| F-16.DURA.T-6 | .0001 | .0001 | .0001 |
| F-16.DURA.T-7 | .0001 | .0001 | .0001 |
| F-16.DURA.T-8 | .0001 | .995 | .995 |
| F-16.DURA.T-9 | .0001 | .0001 | .0001 |
| F-16.DURA.T-10 | .0001 | .482 | .556 |
| F-16.DURA.T-11 | .0001 | .0001 | .0001 |
| F-16.DURA.T-12 | .0001 | .0001 | .0001 |
| F-16.DURA.T-13 | .0001 | .0001 | .0001 |
| F-16.DURA.T-14 | .0001 | .0001 | .0001 |
| F-16.DURA.T-15 | .0001 | .0001 | .0001 |
| F-16.MAVE.T-1 | .0001 | .0001 | .0001 |
| F-16.MAVE.T-2 | .0001 | .0001 | .398 |
| F-16.MAVE.T-3 | .525 | .550 | .0001 |
| F-16.MAVE.T-4 | .995 | .0001 | .0001 |
| F-16.MAVE.T-5 | .535 | .0001 | .0001 |
| F-16.MAVE.T-6 | .0001 | .515 | .542 |
| F-16.MAVE.T-7 | .0001 | .0001 | .540 |
| F-16.MAVE.T-8 | .0001 | .0001 | .0001 |
| F-16.MAVE.T-9 | .505 | .0001 | .593 |
| F-16.MAVE.T-10 | .0001 | .0001 | .0001 |
| F-16.MAVE.T-11 | .431 | .441 | .995 |
| F-16.MAVE.T-12 | .995 | .995 | .380 |
| F-16.MAVE.T-13 | .550 | .389 | .0001 |
| F-16.MAVE.T-14 | .0001 | .502 | .927 |
| F-16.MAVE.T-15 | .0001 | .507 | .848 |
| F-4.MK-82.T-1 | .372 | .380 | .0001 |
| F-4.MK-82.T-2 | .0001 | .0001 | .501 |
| F-4.MK-82.T-3 | .350 | .260 | .0001 |
| F-4.MK-82.T-4 | .380 | .0001 | .0001 |
| F-4.MK-82.T-5 | .372 | .0001 | .0001 |
| F-4.MK-82.T-6 | .0001 | .365 | .399 |
| F-4.MK-82.T-7 | .0001 | .0001 | .995 |
| F-4.MK-82.T-8 | .0001 | .377 | .401 |
| F-4.MK-82.T-9 | .328 | .0001 | .376 |
| F-4.MK-82.T-10 | .0001 | .412 | .457 |
| F-4.MK-82.T-11 | .403 | .438 | .0001 |

| | | | |
|---|---|---|---|
| F-4.MK-82.T-12 | .0001 | .0001 | .535 |
| F-4.MK-82.T-13 | .397 | .257 | .0001 |
| F-4.MK-82.T-14 | .0001 | .237 | .522 |
| F-4.MK-82.T-15 | .0001 | .477 | .522 |
| F-4.MK-84.T-1 | .380 | .370 | .0001 |
| F-4.MK-84.T-2 | .0001 | .0001 | .995 |
| F-4.MK-84.T-3 | .420 | .405 | .0001 |
| F-4.MK-84.T-4 | .420 | .0001 | .0001 |
| F-4.MK-84.T-5 | .408 | .0001 | .0001 |
| F-4.MK-84.T-6 | .0001 | .409 | .395 |
| F-4.MK-84.T-7 | .0001 | .0001 | .420 |
| F-4.MK-84.T-8 | .0001 | .398 | .390 |
| F-4.MK-84.T-9 | .397 | .522 | .417 |
| F-4.MK-84.T-10 | .0001 | .443 | .490 |
| F-4.MK-84.T-11 | .433 | .450 | .0001 |
| F-4.MK-84.T-12 | .0001 | .0001 | .547 |
| F-4.MK-84.T-13 | .995 | .995 | .0001 |
| F-4.MK-84.T-14 | .0001 | .482 | .496 |
| F-4.MK-84.T-15 | .0001 | .488 | .535 |
| F-4.DURA.T-1 | .440 | .415 | .0001 |
| F-4.DURA.T-2 | .0001 | .0001 | .0001 |
| F-4.DURA.T-3 | .0001 | .0001 | .0001 |
| F-4.DURA.T-4 | .0001 | .0001 | .0001 |
| F-4.DURA.T-5 | .0001 | .0001 | .0001 |
| F-4.DURA.T-6 | .0001 | .0001 | .0001 |
| F-4.DURA.T-7 | .0001 | .0001 | .0001 |
| F-4.DURA.T-8 | .0001 | .459 | .955 |
| F-4.DURA.T-9 | .0001 | .0001 | .0001 |
| F-4.DURA.T-10 | .0001 | .905 | .988 |
| F-4.DURA.T-11 | .0001 | .0001 | .0001 |
| F-4.DURA.T-12 | .0001 | .0001 | .0001 |
| F-4.DURA.T-13 | .0001 | .0001 | .0001 |
| F-4.DURA.T-14 | .0001 | .0001 | .0001 |
| F-4.DURA.T-15 | .0001 | .0001 | .0001 |
| F-4.MAVE.T-1 | .0001 | .0001 | .0001 |
| F-4.MAVE.T-2 | .0001 | .0001 | .524 |
| F-4.MAVE.T-3 | .520 | .542 | .0001 |
| F-4.MAVE.T-4 | .525 | .0001 | .0001 |
| F-4.MAVE.T-5 | .995 | .0001 | .0001 |
| F-4.MAVE.T-6 | .0001 | .503 | .529 |
| F-4.MAVE.T-7 | .0001 | .0001 | .526 |
| F-4.MAVE.T-8 | .0001 | .0001 | .0001 |
| F-4.MAVE.T-9 | .493 | .0001 | .502 |
| F-4.MAVE.T-10 | .0001 | .0001 | .0001 |
| F-4.MAVE.T-11 | .455 | .497 | .0001 |

| | | | |
|---|---|---|---|
| F-4.MAVE.T-12 | .0001 | .0001 | .587 |
| F-4.MAVE.T-13 | .476 | .499 | .0001 |
| F-4.MAVE.T-14 | .0001 | .995 | .995 |
| F-4.MAVE.T-15 | .0001 | .575 | .543 |
| F-5.MK-82.T-1 | .575 | .499 | .0001 |
| F-5.MK-82.T-2 | .0001 | .0001 | .318 |
| F-5.MK-82.T-3 | .909 | .919 | .0001 |
| F-5.MK-82.T-4 | .348 | .0001 | .0001 |
| F-5.MK-82.T-5 | .333 | .0001 | .0001 |
| F-5.MK-82.T-6 | .0001 | .349 | .355 |
| F-5.MK-82.T-7 | .0001 | .0001 | .377 |
| F-5.MK-82.T-8 | .0001 | .952 | .389 |
| F-5.MK-82.T-9 | .302 | .0001 | .386 |
| F-5.MK-82.T-10 | .0001 | .927 | .396 |
| F-5.MK-82.T-11 | .387 | .936 | .0001 |
| F-5.MK-82.T-12 | .0001 | .0001 | .477 |
| F-5.MK-82.T-13 | .417 | .982 | .0001 |
| F-5.MK-82.T-14 | .0001 | .965 | .512 |
| F-5.MK-82.T-15 | .0001 | .475 | .483 |
| F-5.MK-84.T-1 | .348 | .356 | .0001 |
| F-5.MK-84.T-2 | .0001 | .0001 | .378 |
| F-5.MK-84.T-3 | .395 | .409 | .0001 |
| F-5.MK-84.T-4 | .415 | .0001 | .0001 |
| F-5.MK-84.T-5 | .412 | .0001 | .0001 |
| F-5.MK-84.T-6 | .0001 | .995 | .995 |
| F-5.MK-84.T-7 | .0001 | .0001 | .411 |
| F-5.MK-84.T-8 | .0001 | .402 | .418 |
| F-5.MK-84.T-9 | .995 | .0001 | .995 |
| F-5.MK-84.T-10 | .0001 | .418 | .499 |
| F-5.MK-84.T-11 | .417 | .475 | .0001 |
| F-5.MK-84.T-12 | .0001 | .0001 | .495 |
| F-5.MK-84.T-13 | .399 | .447 | .0001 |
| F-5.MK-84.T-14 | .0001 | .438 | .477 |
| F-5.MK-84.T-15 | .0001 | .995 | .900 |
| F-5.DURA.T-1 | .0001 | .0001 | .0001 |
| F-5.DURA.T-2 | .0001 | .0001 | .0001 |
| F-5.DURA.T-3 | .0001 | .0001 | .0001 |
| F-5.DURA.T-4 | .0001 | .0001 | .0001 |
| F-5.DURA.T-5 | .0001 | .0001 | .0001 |
| F-5.DURA.T-6 | .0001 | .0001 | .0001 |
| F-5.DURA.T-7 | .0001 | .0001 | .0001 |
| F-5.DURA.T-8 | .0001 | .0001 | .0001 |
| F-5.DURA.T-9 | .0001 | .0001 | .0001 |
| F-5.DURA.T-10 | .0001 | .0001 | .0001 |
| F-5.DURA.T-11 | .0001 | .0001 | .0001 |

| | | | |
|---|---|---|---|
| F-5.DURA.T-12 | .0001 | .0001 | .0001 |
| F-5.DURA.T-13 | .0001 | .0001 | .0001 |
| F-5.DURA.T-14 | .0001 | .0001 | .0001 |
| F-5.DURA.T-15 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-1 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-2 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-3 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-4 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-5 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-6 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-7 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-8 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-9 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-10 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-11 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-12 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-13 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-14 | .0001 | .0001 | .0001 |
| F-5.MAVE.T-15 | .0001 | .0001 | .0001 ; |

**TABLE TVAL (K,T) target values on time bands**

| | P-1 | P-2 | P-3 |
|---|---|---|---|
| T-1 | 200 | 200 | 1 |
| T-2 | 1 | 1 | 200 |
| T-3 | 100 | 100 | 1 |
| T-4 | 150 | 1 | 1 |
| T-5 | 200 | 1 | 1 |
| T-6 | 1 | 200 | 200 |
| T-7 | 1 | 1 | 230 |
| T-8 | 1 | 200 | 200 |
| T-9 | 180 | 1 | 180 |
| T-10 | 1 | 250 | 250 |
| T-11 | 190 | 190 | 1 |
| T-12 | 1 | 1 | 200 |
| T-13 | 210 | 210 | 1 |
| T-14 | 1 | 190 | 190 |
| T-15 | 1 | 200 | 200 ; |

**TABLE TGT(K,T) amount of tgts in each phases**

| | P-1 | P-2 | P-3 |
|---|---|---|---|
| T-1 | 20 | 15 | 10 |
| T-2 | 42 | 16 | 14 |
| T-3 | 12 | 8 | 5 |
| T-4 | 32 | 15 | 12 |
| T-5 | 60 | 40 | 15 |
| T-6 | 50 | 40 | 30 |
| T-7 | 25 | 20 | 15 |
| T-8 | 30 | 30 | 20 |
| T-9 | 40 | 30 | 20 |
| T-10 | 100 | 80 | 50 |
| T-11 | 35 | 40 | 25 |
| T-12 | 25 | 50 | 32 |
| T-13 | 45 | 25 | 20 |
| T-14 | 25 | 20 | 10 |
| T-15 | 60 | 50 | 55; |

**TABLE BOMBS (A,M,K)**

| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 | T15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F-16.MK-82 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| F-16.MK-84 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| F-16.DURA | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| F-16.MAVE | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| F-4.MK-82 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| F-4.MK-84 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| F-4.DURA | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| F-4.MAVE | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| F-5.MK-82 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| F-5.MK-84 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| F-5.DURA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F-5.MAVE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 ; |

**TABLE EA(A,M,K,T) expected attrition**

| | P-1 | P-2 | P-3 |
|---|---|---|---|
| F-16.MK-82.T-1 | .013 | .010 | .010 |
| F-16.MK-82.T-2 | .010 | .010 | .010 |
| F-16.MK-82.T-3 | .018 | .015 | .015 |
| F-16.MK-82.T-4 | .018 | .012 | .012 |
| F-16.MK-82.T-5 | .014 | .010 | .010 |
| F-16.MK-82.T-6 | .010 | .010 | .010 |
| F-16.MK-82.T-7 | .012 | .012 | .013 |
| F-16.MK-82.T-8 | .018 | .014 | .012 |
| F-16.MK-82.T-9 | .012 | .011 | .013 |
| F-16.MK-82.T-10 | .017 | .013 | .011 |
| F-16.MK-82.T-11 | .013 | .012 | .011 |
| F-16.MK-82.T-12 | .011 | .011 | .010 |
| F-16.MK-82.T-13 | .018 | .016 | .010 |
| F-16.MK-82.T-14 | .010 | .010 | .010 |
| F-16.MK-82.T-15 | .012 | .011 | .011 |
| F-16.MK-84.T-1 | .013 | .010 | .010 |
| F-16.MK-84.T-2 | .019 | .020 | .018 |
| F-16.MK-84.T-3 | .018 | .015 | .011 |
| F-16.MK-84.T-4 | .018 | .015 | .012 |
| F-16.MK-84.T-5 | .014 | .010 | .011 |
| F-16.MK-84.T-6 | .013 | .010 | .010 |
| F-16.MK-84.T-7 | .012 | .011 | .013 |
| F-16.MK-84.T-8 | .016 | .014 | .012 |
| F-16.MK-84.T-9 | .015 | .012 | .010 |
| F-16.MK-84.T-10 | .011 | .010 | .010 |
| F-16.MK-84.T-11 | .012 | .010 | .010 |
| F-16.MK-84.T-12 | .015 | .012 | .011 |
| F-16.MK-84.T-13 | .013 | .011 | .010 |
| F-16.MK-84.T-14 | .019 | .015 | .011 |
| F-16.MK-84.T-15 | .013 | .012 | .010 |
| F-16.DURA.T-1 | .019 | .017 | .011 |
| F-16.DURA.T-2 | .016 | .012 | .013 |
| F-16.DURA.T-3 | .011 | .021 | .023 |
| F-16.DURA.T-4 | .010 | .013 | .015 |
| F-16.DURA.T-5 | .018 | .019 | .018 |
| F-16.DURA.T-6 | .011 | .011 | .010 |
| F-16.DURA.T-7 | .010 | .019 | .013 |
| F-16.DURA.T-8 | .012 | .011 | .010 |
| F-16.DURA.T-9 | .016 | .012 | .012 |
| F-16.DURA.T-10 | .019 | .015 | .015 |
| F-16.DURA.T-11 | .015 | .014 | .014 |

| | | | |
|---|---|---|---|
| F-16.DURA.T-12 | .021 | .016 | .017 |
| F-16.DURA.T-13 | .016 | .019 | .019 |
| F-16.DURA.T-14 | .019 | .016 | .012 |
| F-16.DURA.T-15 | .013 | .011 | .010 |
| F-16.MAVE.T-1 | .012 | .011 | .013 |
| F-16.MAVE.T-2 | .010 | .010 | .006 |
| F-16.MAVE.T-3 | .007 | .006 | .019 |
| F-16.MAVE.T-4 | .005 | .021 | .019 |
| F-16.MAVE.T-5 | .005 | .018 | .025 |
| F-16.MAVE.T-6 | .026 | .005 | .003 |
| F-16.MAVE.T-7 | .025 | .009 | .003 |
| F-16.MAVE.T-8 | .019 | .009 | .012 |
| F-16.MAVE.T-9 | .011 | .010 | .010 |
| F-16.MAVE.T-10 | .009 | .012 | .011 |
| F-16.MAVE.T-11 | .006 | .011 | .011 |
| F-16.MAVE.T-12 | .005 | .012 | .008 |
| F-16.MAVE.T-13 | .015 | .012 | .013 |
| F-16.MAVE.T-14 | .012 | .010 | .009 |
| F-16.MAVE.T-15 | .006 | .011 | .013 |
| F-4.MK-82.T-1 | .018 | .015 | .009 |
| F-4.MK-82.T-2 | .007 | .016 | .012 |
| F-4.MK-82.T-3 | .025 | .022 | .006 |
| F-4.MK-82.T-4 | .025 | .012 | .003 |
| F-4.MK-82.T-5 | .022 | .003 | .019 |
| F-4.MK-82.T-6 | .015 | .016 | .012 |
| F-4.MK-82.T-7 | .010 | .010 | .012 |
| F-4.MK-82.T-8 | .010 | .018 | .015 |
| F-4.MK-82.T-9 | .013 | .006 | .009 |
| F-4.MK-82.T-10 | .013 | .015 | .012 |
| F-4.MK-82.T-11 | .006 | .005 | .008 |
| F-4.MK-82.T-12 | .015 | .016 | .012 |
| F-4.MK-82.T-13 | .012 | .010 | .011 |
| F-4.MK-82.T-14 | .021 | .016 | .018 |
| F-4.MK-82.T-15 | .019 | .016 | .015 |
| F-4.MK-84.T-1 | .018 | .015 | .019 |
| F-4.MK-84.T-2 | .013 | .005 | .012 |
| F-4.MK-84.T-3 | .025 | .022 | .005 |
| F-4.MK-84.T-4 | .025 | .005 | .020 |
| F-4.MK-84.T-5 | .022 | .013 | .010 |
| F-4.MK-84.T-6 | .016 | .012 | .019 |
| F-4.MK-84.T-7 | .011 | .023 | .012 |
| F-4.MK-84.T-8 | .010 | .018 | .015 |
| F-4.MK-84.T-9 | .006 | .005 | .006 |
| F-4.MK-84.T-10 | .018 | .016 | .014 |
| F-4.MK-84.T-11 | .009 | .008 | .007 |

| | | | |
|---|---|---|---|
| F-4.MK-84.T-12 | .013 | .012 | .010 |
| F-4.MK-84.T-13 | .015 | .013 | .009 |
| F-4.MK-84.T-14 | .029 | .015 | .006 |
| F-4.MK-84.T-15 | .012 | .012 | .010 |
| F-4.DURA.T-1 | .025 | .022 | .018 |
| F-4.DURA.T-2 | .023 | .016 | .019 |
| F-4.DURA.T-3 | .016 | .025 | .028 |
| F-4.DURA.T-4 | .022 | .015 | .023 |
| F-4.DURA.T-5 | .024 | .026 | .028 |
| F-4.DURA.T-6 | .039 | .037 | .026 |
| F-4.DURA.T-7 | .032 | .029 | .026 |
| F-4.DURA.T-8 | .029 | .032 | .028 |
| F-4.DURA.T-9 | .013 | .012 | .010 |
| F-4.DURA.T-10 | .023 | .020 | .015 |
| F-4.DURA.T-11 | .019 | .012 | .011 |
| F-4.DURA.T-12 | .016 | .013 | .011 |
| F-4.DURA.T-13 | .016 | .013 | .012 |
| F-4.DURA.T-14 | .028 | .023 | .021 |
| F-4.DURA.T-15 | .022 | .023 | .019 |
| F-4.MAVE.T-1 | .023 | .016 | .022 |
| F-4.MAVE.T-2 | .029 | .022 | .028 |
| F-4.MAVE.T-3 | .023 | .021 | .023 |
| F-4.MAVE.T-4 | .030 | .033 | .026 |
| F-4.MAVE.T-5 | .022 | .031 | .032 |
| F-4.MAVE.T-6 | .036 | .039 | .028 |
| F-4.MAVE.T-7 | .029 | .036 | .038 |
| F-4.MAVE.T-8 | .026 | .025 | .033 |
| F-4.MAVE.T-9 | .025 | .019 | .018 |
| F-4.MAVE.T-10 | .023 | .016 | .019 |
| F-4.MAVE.T-11 | .013 | .012 | .010 |
| F-4.MAVE.T-12 | .019 | .016 | .014 |
| F-4.MAVE.T-13 | .013 | .012 | .008 |
| F-4.MAVE.T-14 | .018 | .016 | .014 |
| F-4.MAVE.T-15 | .013 | .015 | .008 |
| F-5.MK-82.T-1 | .025 | .022 | .031 |
| F-5.MK-82.T-2 | .031 | .033 | .028 |
| F-5.MK-82.T-3 | .039 | .031 | .040 |
| F-5.MK-82.T-4 | .035 | .045 | .029 |
| F-5.MK-82.T-5 | .030 | .038 | .037 |
| F-5.MK-82.T-6 | .045 | .034 | .030 |
| F-5.MK-82.T-7 | .036 | .034 | .040 |
| F-5.MK-82.T-8 | .031 | .025 | .038 |
| F-5.MK-82.T-9 | .025 | .023 | .020 |
| F-5.MK-82.T-10 | .019 | .013 | .010 |
| F-5.MK-82.T-11 | .029 | .023 | .021 |

| | | | |
|---|---|---|---|
| F-5.MK-82.T-12 | .009 | .006 | .008 |
| F-5.MK-82.T-13 | .029 | .025 | .023 |
| F-5.MK-82.T-14 | .026 | .028 | .021 |
| F-5.MK-82.T-15 | .017 | .016 | .012 |
| F-5.MK-84.T-1 | .035 | .030 | .028 |
| F-5.MK-84.T-2 | .039 | .031 | .032 |
| F-5.MK-84.T-3 | .039 | .031 | .032 |
| F-5.MK-84.T-4 | .035 | .029 | .024 |
| F-5.MK-84.T-5 | .030 | .031 | .032 |
| F-5.MK-84.T-6 | .039 | .034 | .040 |
| F-5.MK-84.T-7 | .045 | .046 | .032 |
| F-5.MK-84.T-8 | .041 | .035 | .038 |
| F-5.MK-84.T-9 | .032 | .025 | .029 |
| F-5.MK-84.T-10 | .035 | .026 | .024 |
| F-5.MK-84.T-11 | .032 | .019 | .015 |
| F-5.MK-84.T-12 | .016 | .012 | .010 |
| F-5.MK-84.T-13 | .036 | .025 | .019 |
| F-5.MK-84.T-14 | .023 | .019 | .017 |
| F-5.MK-84.T-15 | .015 | .014 | .013 |
| F-5.DURA.T-1 | .052 | .059 | .048 |
| F-5.DURA.T-2 | .056 | .047 | .053 |
| F-5.DURA.T-3 | .041 | .043 | .045 |
| F-5.DURA.T-4 | .059 | .057 | .053 |
| F-5.DURA.T-5 | .051 | .052 | .042 |
| F-5.DURA.T-6 | .048 | .049 | .043 |
| F-5.DURA.T-7 | .051 | .053 | .059 |
| F-5.DURA.T-8 | .057 | .042 | .049 |
| F-5.DURA.T-9 | .032 | .030 | .025 |
| F-5.DURA.T-10 | .023 | .019 | .018 |
| F-5.DURA.T-11 | .035 | .032 | .031 |
| F-5.DURA.T-12 | .045 | .042 | .041 |
| F-5.DURA.T-13 | .040 | .035 | .034 |
| F-5.DURA.T-14 | .006 | .005 | .004 |
| F-5.DURA.T-15 | .032 | .031 | .030 |
| F-5.MAVE.T-1 | .047 | .043 | .041 |
| F-5.MAVE.T-2 | .058 | .052 | .056 |
| F-5.MAVE.T-3 | .054 | .058 | .052 |
| F-5.MAVE.T-4 | .047 | .041 | .043 |
| F-5.MAVE.T-5 | .048 | .045 | .044 |
| F-5.MAVE.T-6 | .056 | .049 | .041 |
| F-5.MAVE.T-7 | .041 | .042 | .058 |
| F-5.MAVE.T-8 | .056 | .052 | .050 |
| F-5.MAVE.T-9 | .023 | .021 | .015 |
| F-5.MAVE.T-10 | .016 | .012 | .011 |
| F-5.MAVE.T-11 | .035 | .031 | .026 |

| | | | | |
|---|---|---|---|---|
| F-5.MAVE.T-12 | .046 | .041 | .036 | |
| F-5.MAVE.T-13 | .042 | .041 | .032 | |
| F-5.MAVE.T-14 | .016 | .012 | .006 | |
| F-5.MAVE.T-15 | .012 | .011 | .010 | ; |

**TABLE HAK(A,M,K,T) number of tgts in each phases**

| | P-1 | P-2 | P-3 |
|---|---|---|---|
| F-16.MK-82.T-1 | 1 | 1 | 0 |
| F-16.MK-82.T-2 | 0 | 0 | 1 |
| F-16.MK-82.T-3 | 1 | 1 | 0 |
| F-16.MK-82.T-4 | 1 | 0 | 0 |
| F-16.MK-82.T-5 | 1 | 0 | 0 |
| F-16.MK-82.T-6 | 0 | 1 | 1 |
| F-16.MK-82.T-7 | 0 | 0 | 1 |
| F-16.MK-82.T-8 | 0 | 1 | 1 |
| F-16.MK-82.T-9 | 1 | 0 | 1 |
| F-16.MK-82.T-10 | 0 | 1 | 1 |
| F-16.MK-82.T-11 | 1 | 1 | 0 |
| F-16.MK-82.T-12 | 0 | 0 | 1 |
| F-16.MK-82.T-13 | 1 | 1 | 0 |
| F-16.MK-82.T-14 | 0 | 1 | 1 |
| F-16.MK-82.T-15 | 0 | 1 | 1 |
| F-16.MK-84.T-1 | 1 | 1 | 0 |
| F-16.MK-84.T-2 | 0 | 0 | 1 |
| F-16.MK-84.T-3 | 1 | 1 | 0 |
| F-16.MK-84.T-4 | 1 | 0 | 0 |
| F-16.MK-84.T-5 | 1 | 0 | 0 |
| F-16.MK-84.T-6 | 0 | 1 | 1 |
| F-16.MK-84.T-7 | 0 | 0 | 1 |
| F-16.MK-84.T-8 | 0 | 1 | 1 |
| F-16.MK-84.T-9 | 1 | 0 | 1 |
| F-16.MK-84.T-10 | 0 | 1 | 1 |
| F-16.MK-84.T-11 | 1 | 1 | 0 |
| F-16.MK-84.T-12 | 0 | 0 | 1 |
| F-16.MK-84.T-13 | 1 | 1 | 0 |
| F-16.MK-84.T-14 | 0 | 1 | 1 |
| F-16.MK-84.T-15 | 0 | 1 | 1 |
| F-16.DURA.T-1 | 1 | 1 | 0 |
| F-16.DURA.T-2 | 0 | 0 | 0 |
| F-16.DURA.T-3 | 0 | 0 | 0 |
| F-16.DURA.T-4 | 0 | 0 | 0 |
| F-16.DURA.T-5 | 0 | 0 | 0 |
| F-16.DURA.T-6 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| F-16.DURA.T-7 | 0 | 0 | 0 |
| F-16.DURA.T-8 | 0 | 1 | 1 |
| F-16.DURA.T-9 | 0 | 0 | 0 |
| F-16.DURA.T-10 | 0 | 1 | 1 |
| F-16.DURA.T-11 | 0 | 0 | 0 |
| F-16.DURA.T-12 | 0 | 0 | 0 |
| F-16.DURA.T-13 | 0 | 0 | 0 |
| F-16.DURA.T-14 | 0 | 0 | 0 |
| F-16.DURA.T-15 | 0 | 0 | 0 |
| F-16.MAVE.T-1 | 0 | 0 | 0 |
| F-16.MAVE.T-2 | 0 | 0 | 1 |
| F-16.MAVE.T-3 | 1 | 1 | 0 |
| F-16.MAVE.T-4 | 1 | 0 | 0 |
| F-16.MAVE.T-5 | 1 | 0 | 0 |
| F-16.MAVE.T-6 | 0 | 1 | 1 |
| F-16.MAVE.T-7 | 0 | 0 | 1 |
| F-16.MAVE.T-8 | 0 | 0 | 0 |
| F-16.MAVE.T-9 | 1 | 0 | 1 |
| F-16.MAVE.T-10 | 0 | 0 | 0 |
| F-16.MAVE.T-11 | 1 | 1 | 0 |
| F-16.MAVE.T-12 | 0 | 0 | 1 |
| F-16.MAVE.T-13 | 1 | 1 | 0 |
| F-16.MAVE.T-14 | 0 | 1 | 1 |
| F-16.MAVE.T-15 | 0 | 1 | 1 |
| F-4.MK-82.T-1 | 1 | 1 | 0 |
| F-4.MK-82.T-2 | 0 | 0 | 1 |
| F-4.MK-82.T-3 | 1 | 1 | 0 |
| F-4.MK-82.T-4 | 1 | 0 | 0 |
| F-4.MK-82.T-5 | 1 | 0 | 0 |
| F-4.MK-82.T-6 | 0 | 1 | 1 |
| F-4.MK-82.T-7 | 0 | 0 | 1 |
| F-4.MK-82.T-8 | 0 | 1 | 1 |
| F-4.MK-82.T-9 | 1 | 0 | 1 |
| F-4.MK-82.T-10 | 0 | 1 | 1 |
| F-4.MK-82.T-11 | 1 | 1 | 0 |
| F-4.MK-82.T-12 | 0 | 0 | 1 |
| F-4.MK-82.T-13 | 1 | 1 | 0 |
| F-4.MK-82.T-14 | 0 | 1 | 1 |
| F-4.MK-82.T-15 | 0 | 1 | 1 |
| F-4.MK-84.T-1 | 1 | 1 | 0 |
| F-4.MK-84.T-2 | 0 | 0 | 1 |
| F-4.MK-84.T-3 | 1 | 1 | 0 |
| F-4.MK-84.T-4 | 1 | 0 | 0 |
| F-4.MK-84.T-5 | 1 | 0 | 0 |
| F-4.MK-84.T-6 | 0 | 1 | 1 |

| | | | |
|---|---|---|---|
| F-4.MK-84.T-7 | 0 | 0 | 1 |
| F-4.MK-84.T-8 | 0 | 1 | 1 |
| F-4.MK-84.T-9 | 1 | 0 | 1 |
| F-4.MK-84.T-10 | 0 | 1 | 1 |
| F-4.MK-84.T-11 | 1 | 1 | 0 |
| F-4.MK-84.T-12 | 0 | 0 | 1 |
| F-4.MK-84.T-13 | 1 | 1 | 0 |
| F-4.MK-84.T-14 | 0 | 1 | 1 |
| F-4.MK-84.T-15 | 0 | 1 | 1 |
| F-4.DURA.T-1 | 1 | 1 | 0 |
| F-4.DURA.T-2 | 0 | 0 | 0 |
| F-4.DURA.T-3 | 0 | 0 | 0 |
| F-4.DURA.T-4 | 0 | 0 | 0 |
| F-4.DURA.T-5 | 0 | 0 | 0 |
| F-4.DURA.T-6 | 0 | 0 | 0 |
| F-4.DURA.T-7 | 0 | 0 | 0 |
| F-4.DURA.T-8 | 0 | 1 | 1 |
| F-4.DURA.T-9 | 0 | 0 | 0 |
| F-4.DURA.T-10 | 0 | 1 | 1 |
| F-4.DURA.T-11 | 0 | 0 | 0 |
| F-4.DURA.T-12 | 0 | 0 | 0 |
| F-4.DURA.T-13 | 0 | 0 | 0 |
| F-4.DURA.T-14 | 0 | 0 | 0 |
| F-4.DURA.T-15 | 0 | 0 | 0 |
| F-4.MAVE.T-1 | 0 | 0 | 0 |
| F-4.MAVE.T-2 | 0 | 0 | 1 |
| F-4.MAVE.T-3 | 1 | 1 | 0 |
| F-4.MAVE.T-4 | 1 | 0 | 0 |
| F-4.MAVE.T-5 | 1 | 0 | 0 |
| F-4.MAVE.T-6 | 0 | 1 | 1 |
| F-4.MAVE.T-7 | 0 | 0 | 1 |
| F-4.MAVE.T-8 | 0 | 0 | 0 |
| F-4.MAVE.T-9 | 1 | 0 | 1 |
| F-4.MAVE.T-10 | 0 | 0 | 0 |
| F-4.MAVE.T-11 | 1 | 1 | 0 |
| F-4.MAVE.T-12 | 0 | 0 | 1 |
| F-4.MAVE.T-13 | 1 | 1 | 0 |
| F-4.MAVE.T-14 | 0 | 1 | 1 |
| F-4.MAVE.T-15 | 0 | 1 | 1 |
| F-5.MK-82.T-1 | 1 | 1 | 0 |
| F-5.MK-82.T-2 | 0 | 0 | 1 |
| F-5.MK-82.T-3 | 1 | 1 | 0 |
| F-5.MK-82.T-4 | 1 | 0 | 0 |
| F-5.MK-82.T-5 | 1 | 0 | 0 |
| F-5.MK-82.T-6 | 0 | 1 | 1 |

| | | | |
|---|---|---|---|
| F-5.MK-82.T-7 | 0 | 0 | 1 |
| F-5.MK-82.T-8 | 0 | 1 | 1 |
| F-5.MK-82.T-9 | 1 | 0 | 1 |
| F-5.MK-82.T-10 | 0 | 1 | 1 |
| F-5.MK-82.T-11 | 1 | 1 | 0 |
| F-5.MK-82.T-12 | 0 | 0 | 1 |
| F-5.MK-82.T-13 | 1 | 1 | 0 |
| F-5.MK-82.T-14 | 0 | 1 | 1 |
| F-5.MK-82.T-15 | 0 | 1 | 1 |
| F-5.MK-84.T-1 | 1 | 1 | 0 |
| F-5.MK-84.T-2 | 0 | 0 | 1 |
| F-5.MK-84.T-3 | 1 | 1 | 0 |
| F-5.MK-84.T-4 | 1 | 0 | 0 |
| F-5.MK-84.T-5 | 1 | 0 | 0 |
| F-5.MK-84.T-6 | 0 | 1 | 1 |
| F-5.MK-84.T-7 | 0 | 0 | 1 |
| F-5.MK-84.T-8 | 0 | 1 | 1 |
| F-5.MK-84.T-9 | 1 | 0 | 1 |
| F-5.MK-84.T-10 | 0 | 1 | 1 |
| F-5.MK-84.T-11 | 1 | 1 | 0 |
| F-5.MK-84.T-12 | 0 | 0 | 1 |
| F-5.MK-84.T-13 | 1 | 1 | 0 |
| F-5.MK-84.T-14 | 0 | 1 | 1 |
| F-5.MK-84.T-15 | 0 | 1 | 1 |
| F-5.DURA.T-1 | 0 | 0 | 0 |
| F-5.DURA.T-2 | 0 | 0 | 0 |
| F-5.DURA.T-3 | 0 | 0 | 0 |
| F-5.DURA.T-4 | 0 | 0 | 0 |
| F-5.DURA.T-5 | 0 | 0 | 0 |
| F-5.DURA.T-6 | 0 | 0 | 0 |
| F-5.DURA.T-7 | 0 | 0 | 0 |
| F-5.DURA.T-8 | 0 | 0 | 0 |
| F-5.DURA.T-9 | 0 | 0 | 0 |
| F-5.DURA.T-10 | 0 | 0 | 0 |
| F-5.DURA.T-11 | 0 | 0 | 0 |
| F-5.DURA.T-12 | 0 | 0 | 0 |
| F-5.DURA.T-13 | 0 | 0 | 0 |
| F-5.DURA.T-14 | 0 | 0 | 0 |
| F-5.DURA.T-15 | 0 | 0 | 0 |
| F-5.MAVE.T-1 | 0 | 0 | 0 |
| F-5.MAVE.T-2 | 0 | 0 | 0 |
| F-5.MAVE.T-3 | 0 | 0 | 0 |
| F-5.MAVE.T-4 | 0 | 0 | 0 |
| F-5.MAVE.T-5 | 0 | 0 | 0 |
| F-5.MAVE.T-6 | 0 | 0 | 0 |

| | | | |
|---|---|---|---|
| F-5.MAVE.T-7 | 0 | 0 | 0 |
| F-5.MAVE.T-8 | 0 | 0 | 0 |
| F-5.MAVE.T-9 | 0 | 0 | 0 |
| F-5.MAVE.T-10 | 0 | 0 | 0 |
| F-5.MAVE.T-11 | 0 | 0 | 0 |
| F-5.MAVE.T-12 | 0 | 0 | 0 |
| F-5.MAVE.T-13 | 0 | 0 | 0 |
| F-5.MAVE.T-14 | 0 | 0 | 0 |
| F-5.MAVE.T-15 | 0 | 0 | 0; |

**PARAMETER TOTAC(A)** number of allocated aircraft types

```
/ F-16 = 50
 F-4  = 50
 F-5  = 50/;
```

**PARAMETER TOTWPN(M)** number of weapons types

```
/ MK-82 = 10000
 MK-84 =  8000
 DURA  =  5000
 MAVE  =  5000 /;
```

**PARAMETER SR(A)** sortie rate for each type of aircraft

```
/ F-16 = 3
 F-4  = 2.5
 F-5  = 1.5 /;
```

**PARAMETER PHASES(T)** number of days in each phase

```
/ P-1 = 3
 P-2 = 7
 P-3 = 10 /;
```

**PARAMETER TS (A,M,K,T);**

```
TS(A,M,K,T)=(1-(1-EA(A,M,K,T))**(SR(A)*PHASES(T)))/EA(A,M,K,T);

DISPLAY TS;
```

**SCALAR SEM** / 1.2 /;

**VARIABLES**

| | |
|---|---|
| Z | total tvd |
| X(A,M,K,T) | number of sorties flown |
| WPNUSE(A,M,K) | weapon use |
| LA1(A) | number of attrited aircraft in phase 1 |
| LA2(A) | number of attrited aircraft in phase 2 |
| LA3(A) | number of attrited aircraft in phase 3 |
| TLAC(A) | total number of attrited aircraft |
| | ; |

POSITIVE VARIABLE X
WPNUSE
LA1
LA2
LA3
TLAC;

**EQUATIONS**

| | |
|---|---|
| TVD | target value destroyed |
| AC1(A) | total available aircraft in first period |
| AC2(A) | total available aircraft in other phases |
| LOSTAC1(A) | number of attrited aircraft in phase 1 |
| LOSTAC2(A) | number of attrited aircraft in phase 2 |
| LOSTAC3(A) | number of attrited aircraft in phase 3 |
| TOTLAC(A) | total number of attrited aircraft |
| WEAPON(M) | total weapons |
| TARGET(K,T) | total targets |
| WEAPONUSE(A,M,K) | weapon usage of involved aircraft ; |

```
TVD..    Z =E=        SUM((A,M,K,T),X(A,M,K,T)*YIELD

                      (A,M,K,T)*TVAL(K,T)*HAK(A,M,K,T));

AC1(A)..
SUM((M,K,T)$(ORD(T)=1),(X(A,M,K,T)/TS(A,M,K,T))*HAK(A,M,K,T))
                                              =L=TOTAC(A);

AC2(A)..
SUM((M,K,T)$(ORD(T)>=2),(X(A,M,K,T)/TS(A,M,K,T))*HAK(A,M,K,T))

+SUM((M,K,T)$(ORD(T)=1),X(A,M,K,T)*EA(A,M,K,T)*HAK(A,M,K,T))+

SUM((M,K,T)$(ORD(T)=2),X(A,M,K,T)*EA(A,M,K,T)*HAK(A,M,K,T))
                                              =L=TOTAC(A);

LOSTAC1(A)..      LA1(A)- SUM((M,K,T)$(ORD(T)=1),X(A,M,K,T)*
                              EA(A,M,K,T)*HAK(A,M,K,T))=E=0;

LOSTAC2(A)..      LA2(A)- SUM((M,K,T)$(ORD(T)=2),X(A,M,K,T)*
                              EA(A,M,K,T)*HAK(A,M,K,T))=E=0;

LOSTAC3(A)..      LA3(A)- SUM((M,K,T)$(ORD(T)=3),X(A,M,K,T)*
                              EA(A,M,K,T)*HAK(A,M,K,T))=E=0;

TOTLAC(A)..       TLAC(A)-LA1(A)-LA2(A)- LA3(A)=E=0;

WEAPON(M)..       SUM((A,K,T),X(A,M,K,T)*BOMBS(A,M,K)*HAK(A,M,K,T))
                                              =L= TOTWPN(M);

TARGET(K,T)..         SUM((A,M),X(A,M,K,T)*YIELD(A,M,K,T)*
                              HAK(A,M,K,T)) =L= TGT(K,T)*SEM;

WEAPONUSE(A,M,K)..    WPNUSE(A,M,K)- SUM((T),
                      X(A,M,K,T)*BOMBS(A,M,K)*HAK(A,M,K,T)) =E=0 ;


MODEL HAKAN1   /ALL/ ;
option limrow = 1000, limcol = 1000;

SOLVE HAKAN1 USING LP MAXIMIZING Z;
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# APPENDIX E: SORTIE ALLOCATIONS

Sortie Allocations GOOD WEATHER, AIR SUPREMACY, LOW ATTRITION

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.MK-82.T-2 .P-3 | 40.7767 |
| F-16.MK-82.T-6 .P-2 | 25.5481 |
| F-16.MK-82.T-6 .P-3 | 87.8049 |
| F-16.MK-84.T-4 .P-1 | 6.3300 |
| F-16.MK-84.T-5 .P-1 | 173.0769 |
| F-16.MK-84.T-7 .P-3 | 43.6893 |
| F-16.MK-84.T-9 .P-1 | 124.6753 |
| F-16.MK-84.T-9 .P-3 | 57.8313 |
| F-16.MK-84.T-10.P-2 | 115.1840 |
| F-16.MK-84.T-11.P-1 | 97.6744 |
| F-16.MK-84.T-11.P-2 | 105.4945 |
| F-16.DURA .T-8 .P-2 | 16.8812 |
| F-4 .MK-82.T-3 .P-1 | 41.1429 |
| F-4 .MK-82.T-3 .P-2 | 36.9231 |
| F-4 .MK-82.T-12.P-3 | 71.7757 |
| F-4 .MK-82.T-13.P-1 | 136.0202 |
| F-4 .MK-82.T-13.P-2 | 116.7315 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 48.8878 |
| F-5 .MK-82.T-10.P-3 | 151.5152 |
| F-5 .MK-84.T-4 .P-1 | 86.2611 |
| F-5 .MK-84.T-6 .P-2 | 42.9775 |
| F-5 .MK-84.T-8 .P-2 | 47.7691 |
| F-5 .MK-84.T-8 .P-3 | 57.4163 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 73.3333 |

Sortie Allocations BAD WEATHER, NO AIR SUPREMACY, HIGH ATTRITION

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-11.P-1 | 49.7842 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 4.8573 |
| F-4 .MK-82.T-11.P-1 | 50.9752 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | .8745 |
| F-5 .MK-84.T-15.P-3 | 68.7567 |

Sortie Allocations when the cost of F-4 aircraft is 20 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-15.P-3 | 30.6667 |
| F-4 .MK-82.T-7 .P-3 | 18.0905 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 14.9408 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-4 .MAVE .T-15.P-3 | 25.4630 |
| F-5 .MK-82.T-10.P-2 | 88.9737 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 29.0758 |

Sortie Allocations for F-16=30 units, F-4=10 and Budget =800 units.

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 24.0293 |
| F-16.MAVE .T-15.P-3 | 49.9828 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 76.1337 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-5 .P-1 | 72.3618 |
| F-4 .MAVE .T-11.P-1 | 92.3077 |
| F-4 .MAVE .T-11.P-2 | 96.5795 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 29.2330 |
| F-5 .MK-84.T-9 .P-1 | 48.2412 |
| F-5 .MK-84.T-9 .P-3 | 9.7996 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 26.2384 |

Sortie Allocations F-16=30 units, F-4=21 and Budget =800 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-15.P-3 | 20.6294 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 0.1722 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-4 .MAVE .T-15.P-3 | 89.3302 |
| F-5 .MK-82.T-10.P-2 | 103.3918 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |

Sortie Allocations F-16=30 units, F-4=22 and Budget =800 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 7.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 8.6432 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 47.3475 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 0.1722 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 21.2963 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-15.P-3 | 108.0490 |
| F-5 .MK-82.T-10.P-2 | 103.3918 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |

Sortie Allocations F-16=30 units, F-4=23 and Budget =800 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 11.0171 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 15.5913 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 0.1722 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-15.P-3 | 97.1981 |
| F-5 .MK-82.T-10.P-2 | 103.3918 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |

Sortie Allocations F-16=30 units, F-4=24 and Budget =800 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 1.6061 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 25.7488 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 0.1722 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-15.P-3 | 81.3352 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |

Sortie Allocations F-16=30 units, F-4=25 and Budget =800 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 27.4823 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 21.0212 |
| F-4 .MAVE .T-15.P-3 | 78.6280 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 1 where the cost of F-4 is 12 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 47.2423 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 32.3705 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-5 .P-1 | 72.3618 |
| F-4 .MAVE .T-11.P-2 | 96.5795 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-4 .MAVE .T-15.P-3 | 121.5470 |
| F-5 .MK-82.T-10.P-2 | 71.9576 |
| F-5 .MK-84.T-9 .P-1 | 29.3918 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |

Sortie Allocations. Analysis of Suggestion 1 where the cost of F-4 is 13 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.MK-82.T-2 .P-3 | 12.9994 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-15.P-3 | 71.3524 |
| F-4 .MK-82.T-7 .P-3 | 18.0905 |
| F-4 .MK-82.T-9 .P-1 | 146.3415 |
| F-4 .MK-82.T-9 .P-3 | 63.8298 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-82.T-12.P-3 | 71.7757 |
| F-4 .MK-84.T-2 .P-3 | 11.5018 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 3.2724 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-5 .P-1 | 72.3618 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 100.3652 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 6.1035 |

Sortie Allocations. Analysis of Suggestion 1 where the cost of F-4 is 14 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-15.P-3 | 24.1712 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 25.8527 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-11.P-1 | 92.3077 |
| F-4 .MAVE .T-11.P-2 | 96.5795 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 78.3207 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 50.5587 |

Sortie Allocations. Analysis of Suggestion 1 where the cost of F-4 is 15 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-4 .MK-82.T-11.P-2 | 18.7136 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 37.4207 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-11.P-2 | 80.0874 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 67.0272 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 73.3333 |

Sortie Allocations. Analysis of Suggestion 1 where the cost of F-4 is 16 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-4 .MK-82.T-11.P-2 | 51.0217 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 37.4207 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-11.P-2 | 51.6147 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 67.0272 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 73.3333 |

Sortie Allocations. Analysis of Suggestion 2 where the cost of F-4 is 18 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 12.8081 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-9 .P-1 | 4.4043 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-4 .MK-82.T-7 .P-3 | 18.0905 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 115.3044 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 43.3842 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-3 .P-2 | 2.7808 |
| F-5 .MK-82.T-10.P-2 | 61.2053 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 73.3333 |

Sortie Allocations. Analysis of Suggestion 2 where the cost of F-4 is 19 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-11.P-1 | 44.7357 |
| F-4 .MK-82.T-11.P-1 | 56.3745 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 37.4207 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-5 .MK-82.T-10.P-2 | 67.0272 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 73.3333 |

Sortie Allocations. Analysis of Suggestion 2 where the cost of F-4 is 20 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P- | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-15.P-3 | 30.6667 |
| F-4 .MK-82.T-7 .P-3 | 18.0905 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 14.9408 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-4 .MAVE .T-15.P-3 | 25.4630 |
| F-5 .MK-82.T-10.P-2 | 88.9737 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |
| F-5 .MK-84.T-15.P-3 | 29.0758 |

Sortie Allocations. Analysis of Suggestion 2 where the cost of F-4 is 21 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-3 .P-2 | 17.4545 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-15.P-3 | 20.6294 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-2 | 0.1722 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-12.P-3 | 65.4174 |
| F-4 .MAVE .T-14.P-2 | 24.1206 |
| F-4 .MAVE .T-14.P-3 | 12.0603 |
| F-4 .MAVE .T-15.P-3 | 89.3302 |
| F-5 .MK-82.T-10.P-2 | 103.3918 |
| F-5 .MK-84.T-15.P-2 | 60.3015 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 27 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 27.4823 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 13.7933 |
| F-4 .MAVE .T-15.P-3 | 78.6280 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 28 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 77.8302 |
| F-4 .MK-82.T-11.P-1 | 104.2184 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-9 .P-3 | 57.5540 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 10.7546 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 29 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 77.8302 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 9.1696 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 30 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 77.8302 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 8.1238 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 31 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 77.8302 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 7.1454 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 32 units

| | LEVEL |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 77.8302 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-12.P-3 | 70.2011 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 6.2282 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

Sortie Allocations. Analysis of Suggestion 3 where the cost of F-4 is 33 units

| | **LEVEL** |
|---|---|
| F-16.MK-82.T-1 .P-1 | 24.1206 |
| F-16.MK-82.T-1 .P-2 | 18.0905 |
| F-16.MK-84.T-12.P-3 | 73.1429 |
| F-16.DURA .T-8 .P-2 | 36.1809 |
| F-16.DURA .T-8 .P-3 | 24.1206 |
| F-16.MAVE .T-3 .P-1 | 27.4286 |
| F-16.MAVE .T-4 .P-1 | 38.5930 |
| F-16.MAVE .T-5 .P-1 | 134.5794 |
| F-16.MAVE .T-6 .P-2 | 93.2039 |
| F-16.MAVE .T-6 .P-3 | 66.4207 |
| F-16.MAVE .T-7 .P-3 | 33.3333 |
| F-16.MAVE .T-9 .P-3 | 40.4722 |
| F-16.MAVE .T-11.P-1 | 97.4478 |
| F-16.MAVE .T-14.P-3 | 12.9450 |
| F-16.MAVE .T-15.P-3 | 77.8302 |
| F-4 .MK-82.T-11.P-2 | 109.5890 |
| F-4 .MK-84.T-2 .P-3 | 16.8844 |
| F-4 .MK-84.T-9 .P-1 | 120.9068 |
| F-4 .MK-84.T-13.P-1 | 54.2714 |
| F-4 .MK-84.T-13.P-2 | 30.1508 |
| F-4 .DURA .T-10.P-3 | 60.7287 |
| F-4 .MAVE .T-14.P-2 | 5.4279 |
| F-5 .MK-82.T-10.P-2 | 103.5599 |
| F-5 .MK-84.T-15.P-2 | 60.1424 |

# APPENDIX F: TARGET KILL LEVELS

**Table 23.Target Destruction Levels for bad weather with no air supremacy**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| **T-11.P-2** | **NONE** | **48.00** |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **NONE** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **27.73** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 24. Target Destruction Levels where cost of F-4 is 23 units**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **6.05** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| T-14.P-2 | 24.00 | 24.00 |
| T-14.P-3 | 12.00 | 12.00 |
| T-15.P-2 | 60.00 | 60.00 |
| T-15.P-3 | 66.00 | 66.00 |

**Table 25. Target Destruction Levels where cost of F-4 is 24 units**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| T-3 .P-2 | **0.88** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-3 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| T-14.P-2 | 24.00 | 24.00 |
| T-14.P-3 | 12.00 | 12.00 |
| T-15.P-2 | 60.00 | 60.00 |
| T-15.P-3 | 66.00 | 66.00 |

**Table 26. Target Destruction Levels where cost of F-4 is 25 units**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| T-3 .P-2 | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **20.91** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 27. Target Destruction Levels for Project 3 F-4 Cost = 27**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **13.72** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 28. Target Destruction Levels for Project 3 F-4 Cost = 28**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **10.70** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 29. Target Destruction Levels for Project 3 F-4 Cost = 29**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **9.12** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 30. Target Destruction Levels for Project 3 F-4 Cost = 30**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **8.08** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 31. Target Destruction Levels for Project 3 F-4 Cost = 31**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| T-3 .P-2 | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| T-14.P-2 | **7.10** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| T-15.P-2 | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 32. Target Destruction Levels for Project 3 F-4 Cost = 32**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **6.19** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 33. Target Destruction Levels for Project 3 F-4 Cost = 33**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| T-11.P-2 | 48.00 | 48.00 |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **5.40** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **59.84** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

**Table 34. Target Destruction Levels for the Second Allocation Plan**

| | Destroyed | Total Number of Targets |
|---|---|---|
| T-1 .P-1 | 24.00 | 24.00 |
| T-1 .P-2 | 18.00 | 18.00 |
| T-2 .P-3 | 16.80 | 16.80 |
| T-3 .P-1 | 14.40 | 14.40 |
| **T-3 .P-2** | **NONE** | **9.60** |
| T-4 .P-1 | 38.40 | 38.40 |
| T-5 .P-1 | 72.00 | 72.00 |
| T-6 .P-2 | 48.00 | 48.00 |
| T-6 .P-3 | 36.00 | 36.00 |
| T-7 .P-3 | 18.00 | 18.00 |
| T-8 .P-2 | 36.00 | 36.00 |
| T-8 .P-3 | 24.00 | 24.00 |
| T-9 .P-1 | 48.00 | 48.00 |
| T-9 .P-3 | 24.00 | 24.00 |
| T-10.P-2 | 96.00 | 96.00 |
| T-10.P-3 | 60.00 | 60.00 |
| T-11.P-1 | 42.00 | 42.00 |
| **T-11.P-2** | **24.26** | **48.00** |
| T-12.P-3 | 38.40 | 38.40 |
| T-13.P-1 | 54.00 | 54.00 |
| T-13.P-2 | 30.00 | 30.00 |
| **T-14.P-2** | **NONE** | **24.00** |
| T-14.P-3 | 12.00 | 12.00 |
| **T-15.P-2** | **39.95** | **60.00** |
| T-15.P-3 | 66.00 | 66.00 |

# APPENDIX G: AIRCRAFT-WEAPON ALLOCATIONS

**Table 35. Aircraft-Weapon Allocations where cost of F-4 is 21 units**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50+.34 | 33.29 | 506.53 | NONE | 241.20 | 2589.85 |
| **F-4** | 50+37.60 | 67.52 | 3420.91 | 3357.20 | 365.40 | 1145.57 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 122.70 | 4547.80 | 3719.02 | 606.61 | 3735.42 |

**Table 36. Aircraft Attrition where cost of F-4 is 21 units**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 11.49 | 8.08 | 33.29 |
| **F-4** | 21.64 | 13.29 | 32.58 | 67.52 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 35.36 | 46.67 | 40.66 | **122.70** |

**Table 37. Aircraft-Weapon Allocations where cost of F-4 is 22 units**

| Aircraft | Total Usage | Total Attr. | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 32.90 | 506.53 | NONE | 241.20 | 2595.60 |
| **F-4** | 50+36.36 | 65.88 | 3420.91 | 3925.37 | 365.40 | 920.79 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 120.67 | 4547.80 | 4287.17 | 606.60 | 3516.39 |

**Table 38. Aircraft Attrition where cost of F-4 is 22 units**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 11.49 | 7.69 | 32.90 |
| **F-4** | 21.64 | 13.29 | 30.94 | 65.88 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 35.36 | 46.67 | 38.64 | **120.67** |

**Table 39. Aircraft-Weapon Allocations where cost of F-4 is 23 units**

| Aircraft | Total Usage | Total Attr. | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 33.42 | 506.53 | NONE | 241.20 | 2598.67 |
| **F-4** | 50+36.36 | 64.32 | 3420.91 | 4199.62 | 365.40 | 727.91 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 119.62 | 4547.80 | 4561.42 | 606.60 | 3326.58 |

**Table 40. Aircraft Attrition where cost of F-4 is 23 units**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 11.11 | 8.59 | 33.42 |
| **F-4** | 21.64 | 13.29 | 29.38 | 64.32 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 35.36 | 46.28 | 37.98 | **119.62** |

**Table 41. Aircraft-Weapon Allocations where cost of F-4 is 24 units**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 34.17 | 506.53 | NONE | 241.20 | 2603.15 |
| **F-4** | 50+33.33 | 63.05 | 3420.91 | 4199.62 | 365.40 | 632.73 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 119.11 | 4547.80 | 4561.42 | 606.60 | 3235.88 |

**Table 42. Aircraft Attrition where cost of F-4 is 24 units**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 10.54 | 9.91 | 34.17 |
| **F-4** | 21.64 | 13.29 | 28.11 | 63.05 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 35.36 | 45.72 | 38.03 | **119.11** |

**Table 43. Aircraft-Weapon Allocations where cost of F-4 is 25 units**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50 | 34.30 | 506.53 | NONE | 241.20 | 2603.91 |
| F-4 | 50+32 | 62.30 | 3420.91 | 4199.62 | 364.37 | 597.89 |
| F-5 | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| TOTAL | | 118.49 | 4548.81 | 4560.47 | 605.57 | 3201.80 |

**Table 44. Aircraft Attrition where cost of F-4 is 25 units**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 13.71 | 10.44 | 10.14 | 34.30 |
| F-4 | 21.64 | 12.76 | 27.89 | 62.30 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 35.36 | 45.09 | 38.04 | **118.49** |

**Table 45. Aircraft-Weapon Allocations for Project 1 F-4 Cost = 12**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50+.96 | 33.78 | 506.53 | NONE | 241.20 | 2486.12 |
| F-4 | 50+64.25 | 84.44 | NONE | 1782.58 | 558.59 | 2352.51 |
| F-5 | 50 | 27.20 | 431.74 | 538.15 | NONE | NONE |
| TOTAL | | 145.42 | 938.27 | 2320.73 | 799.79 | 4838.63 |

**Table 46. Aircraft Attrition for Project 1 F-4 Cost = 12**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 12.83 | 11.49 | 9.45 | 33.78 |
| F-4 | 26.89 | 25.84 | 31.70 | 84.44 |
| F-5 | 9.40 | 17.79 | NONE | 27.20 |
| TOTAL | 49.13 | 55.13 | 41.15 | **145.42** |

Table 47. Aircraft-Weapon Allocations for Project 1 F-4 Cost = 13

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 33.46 | 662.52 | NONE | 241.20 | 1886.71 |
| **F-4** | 50+61.53 | 91.95 | 8221.51 | 1151.08 | 384.00 | 651.25 |
| **F-5** | 50 | 22.28 | 602.19 | 398.43 | NONE | NONE |
| **TOTAL** | | 147.70 | 9486.23 | 1549.51 | 625.21 | 2537.97 |

Table 48. Aircraft Attrition for Project 1 F-4 Cost = 13

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 6.98 | 11.49 | 14.98 | 33.46 |
| F-4 | 49.33 | 13.91 | 28.70 | 91.95 |
| F-5 | NONE | 21.48 | .79 | 22.28 |
| TOTAL | 56.32 | 46.89 | 44.48 | **147.70** |

Table 49. Aircraft-Weapon Allocations for Project 1 F-4 Cost = 14

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50+. 81 | 33.75 | 506.53 | NONE | 241.20 | 2611.1 |
| **F-4** | 50+55.40 | 77.36 | NONE | 3357.20 | 519.48 | 1742.91 |
| **F-5** | 50 | 25.19 | 469.92 | 665.16 | NONE | NONE |
| **TOTAL** | | 136.32 | 976.45 | 4022.36 | 760.68 | 4354.01 |

Table 50. Aircraft Attrition for Project 1 F-4 Cost = 14

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 13.71 | 11.49 | 8.54 | 33.75 |
| F-4 | 27.39 | 24.53 | 25.43 | 77.36 |
| F-5 | NONE | 18.62 | 6.57 | 25.19 |
| TOTAL | 41.10 | 54.65 | 40.55 | **136.32** |

### Table 51. Aircraft-Weapon Allocations for Project 1 F-4 Cost = 15

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50+3.46 | 36.46 | 506.53 | NONE | 241.20 | 3150.76 |
| F-4 | 50+46.39 | 66.63 | 299.41 | 3357.20 | 588.89 | 1090.11 |
| F-5 | 50 | 26.68 | 402.16 | 801.80 | NONE | NONE |
| TOTAL | | 129.79 | 1208.11 | 4159.01 | 830.10 | 4240.88 |

### Table 52. Aircraft Attrition for Project 1 F-4 Cost = 15

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 19.56 | 11.49 | 5.40 | 36.46 |
| F-4 | 15.39 | 25.80 | 25.43 | 66.63 |
| F-5 | NONE | 17.15 | 9.53 | 26.68 |
| TOTAL | 34.95 | 54.46 | 40.37 | **129.79** |

### Table 53. Aircraft-Weapon Allocations for Project 1 F-4 Cost = 16

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50+3.46 | 36.46 | 506.53 | NONE | 241.20 | 3150.76 |
| F-4 | 50+43.49 | 64.83 | 816.34 | 3357.20 | 588.89 | 919.27 |
| F-5 | 50 | 26.68 | 402.16 | 801.80 | NONE | NONE |
| TOTAL | | 129.79 | 1208.11 | 4159.01 | 830.10 | 4240.88 |

### Table 54. Aircraft Attrition for Project 1 F-4 Cost = 16

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 19.56 | 11.49 | 5.40 | 36.46 |
| F-4 | 15.39 | 24.00 | 25.43 | 64.83 |
| F-5 | NONE | 17.15 | 9.53 | 26.68 |
| TOTAL | 34.95 | 52.66 | 40.37 | **127.99** |

**Table 55. Aircraft-Weapon Allocations for Project 2 F-4 Cost = 18**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 33.86 | 506.53 | NONE | 241.20 | 2507.46 |
| **F-4** | 50+44.44 | 67.40 | 3710.36 | 2599.33 | 624.67 | 609.58 |
| **F-5** | 50 | 26.79 | 383.91 | 801.80 | NONE | NONE |
| **TOTAL** | | 128.05 | 4600.81 | 3401.14 | 865.88 | 3117.05 |

**Table 56. Aircraft Attrition for Project 2 F-4 Cost = 18**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 14.19 | 11.21 | 8.45 | 33.86 |
| **F-4** | 21.31 | 21.93 | 24.15 | 67.40 |
| **F-5** | NONE | 17.26 | 9.53 | 26.79 |
| **TOTAL** | 35.51 | 50.41 | 42.13 | **128.05** |

**Table 57. Aircraft-Weapon Allocations for Project 2 F-4 Cost = 19**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50+0.30 | 33.29 | 506.53 | NONE | 241.20 | 2734.49 |
| **F-4** | 50+41.62 | 64.95 | 2655.41 | 3357.20 | 588.89 | 609.58 |
| **F-5** | 50 | 26.68 | 402.16 | 801.80 | NONE | NONE |
| **TOTAL** | | 124.94 | 3564.11 | 4159.01 | 830.10 | 3344.08 |

**Table 58. Aircraft Attrition for Project 2 F-4 Cost = 19**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 16.39 | 11.49 | 5.40 | 33.29 |
| **F-4** | 18.77 | 20.74 | 25.43 | 64.95 |
| **F-5** | NONE | 17.15 | 9.53 | 26.68 |
| **TOTAL** | 35.17 | 49.39 | 40.37 | **124.94** |

**Table 59. Aircraft-Weapon Allocations for Project 2 F-4 Cost = 20**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 33.60 | 506.53 | NONE | 241.20 | 2450.08 |
| **F-4** | 50+44 | 67.53 | 3710.36 | 3357.20 | 454.01 | 762.36 |
| **F-5** | 50 | 23.78 | 533.84 | 536.26 | NONE | NONE |
| **TOTAL** | | 124.92 | 4750.74 | 3893.47 | 695.22 | 3212.44 |

**Table 60. Aircraft Attrition for Project 2 F-4 Cost = 20**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 11.49 | 8.39 | 33.60 |
| **F-4** | 21.64 | 16.24 | 29.64 | 67.53 |
| **F-5** | NONE | 20.00 | 3.77 | 23.78 |
| **TOTAL** | 35.36 | 47.75 | 41.81 | **124.92** |

**Table 61. Aircraft-Weapon Allocations for Project 2 F-4 Cost = 21**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50 | 33.29 | 506.53 | NONE | 241.20 | 2589.85 |
| **F-4** | 50+44 | 67.52 | 3420.92 | 3357.20 | 365.40 | 1145.57 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 122.70 | 4547.80 | 3719.01 | 606.61 | 3735.42 |

**Table 62. Aircraft Attrition for Project 2 F-4 Cost = 21**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 13.71 | 11.49 | 8.08 | 33.29 |
| **F-4** | 21.64 | 13.29 | 32.58 | 67.52 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 35.36 | 46.67 | 40.66 | **122.70** |

**Table 63. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 27**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50 | 34.30 | 506.53 | NONE | 241.20 | 2603.91 |
| F-4 | 50+29.62 | 61.15 | 3420.92 | 4199.62 | 364.37 | 554.52 |
| F-5 | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| TOTAL | | 117.34 | 4548.81 | 4560.47 | 605.57 | 3158.44 |

**Table 64. Aircraft Attrition for Project 3 F-4 Cost = 27**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 13.71 | 10.44 | 10.14 | 34.30 |
| F-4 | 21.64 | 11.60 | 27.89 | 61.15 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 35.36 | 43.93 | 38.04 | **117.34** |

**Table 65. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 28**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50 | 40.85 | 506.53 | NONE | 241.20 | 2906.00 |
| F-4 | 50+29.62 | 54.37 | 3420.92 | 4199.62 | 364.37 | 64.5287 |
| F-5 | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| TOTAL | | 117.11 | 4548.81 | 4560.47 | 605.57 | 2970.53 |

**Table 66. Aircraft Attrition for Project 3 F-4 Cost = 28**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 13.71 | 10.44 | 16.68 | 40.85 |
| F-4 | 21.64 | 11.11 | 21.60 | 54.37 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 35.36 | 43.45 | 38.29 | **117.11** |

**Table 67. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 29**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50 | 50.74 | 506.53 | NONE | 241.20 | 3733.52 |
| F-4 | 50+29.62 | 44.41 | 1753.42 | 3508.97 | 364.37 | 55.01 |
| F-5 | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| TOTAL | | 117.04 | 2881.30 | 3869.82 | 605.57 | 3788.53 |

**Table 68. Aircraft Attrition for Project 3 F-4 Cost = 29**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 19.56 | 10.44 | 20.73 | 50.74 |
| F-4 | 15.39 | 10.86 | 18.15 | 44.41 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 34.95 | 43.19 | 38.89 | **117.04** |

**Table 69. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 30**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50+16.72 | 50.74 | 506.53 | NONE | 241.20 | 3733.52 |
| F-4 | 50+9.94 | 44.24 | 1753.42 | 3508.97 | 364.37 | 48.47 |
| F-5 | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| TOTAL | | 116.87 | 2881.30 | 3869.82 | 605.57 | 3781.99 |

**Table 70. Aircraft Attrition for Project 3 F-4 Cost = 30**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 19.56 | 10.44 | 20.73 | 50.74 |
| F-4 | 15.39 | 10.69 | 18.15 | 44.24 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 34.95 | 43.03 | 38.89 | **116.87** |

## Table 71. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 31

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50+16.72 | 50.74 | 506.53 | NONE | 241.20 | 3733.52 |
| **F-4** | 50+9.62 | 44.09 | 1753.42 | 3508.97 | 364.37 | 42.87 |
| **F-5** | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| **TOTAL** | | 116.72 | 2881.30 | 3869.82 | 605.57 | 3776.39 |

## Table 72. Aircraft Attrition for Project 3 F-4 Cost = 31

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 19.56 | 10.44 | 20.73 | 50.74 |
| **F-4** | 15.39 | 10.54 | 18.15 | 44.09 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 34.95 | 42.87 | 38.89 | **116.72** |

## Table 73. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 32

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1** | 50+16.72 | 50.74 | 506.53 | NONE | 241.20 | 3733.52 |
| **F-4** | 50+9.32 | 43.94 | 1753.42 | 3508.97 | 364.37 | 37.36 |
| **F-5** | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| **TOTAL** | | 116.57 | 2881.3 | 3869.82 | 605.57 | 3770.88 |

## Table 74. Aircraft Attrition for Project 3 F-4 Cost = 32

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1** | 19.56 | 10.44 | 20.73 | 50.74 |
| **F-4** | 15.39 | 10.39 | 18.15 | 43.94 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 34.95 | 42.72 | 38.89 | **116.57** |

**Table 75. Aircraft-Weapon Allocations for Project 3 F-4 Cost = 33**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1 | 50+16.72 | 58.79 | 506.53 | 585.14 | 241.20 | 3733.52 |
| F-4 | 50+9.32 | 36.79 | 1753.42 | 2666.56 | 364.37 | 32.56 |
| F-5 | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| TOTAL | | 117.47 | 2881.31 | 3612.55 | 605.57 | 3766.09 |

**Table 76. Aircraft Attrition for Project 3 F-4 Cost = 33**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1 | 19.56 | 10.44 | 28.78 | 58.79 |
| F-4 | 15.39 | 10.26 | 11.13 | 36.79 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 34.95 | 42.59 | 39.91 | **117.47** |

**Table 77. Aircraft-Weapon Allocations for the Second Allocation Plan**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1D | 50 | 37.50 | 506.53 | NONE | 241.20 | 2656.99 |
| F-4 | 50 | 40.24 | 886.45 | 3508.97 | 364.37 | NONE |
| F-5 | 50 | 24.62 | 621.35 | 496.44 | NONE | NONE |
| TOTAL | | 102.36 | 2014.35 | 4005.41 | 605.57 | 2656.99 |

**Table 78. Aircraft Attrition for the Second Allocation Plan**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1D | 16.18 | 8.55 | 12.76 | 37.50 |
| F-4 | 15.39 | 6.68 | 18.15 | 40.24 |
| F-5 | NONE | 19.08 | 5.53 | 24.62 |
| TOTAL | 31.58 | 34.32 | 36.45 | **102.36** |

### Table 79. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 12

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50 | 35.04 | NONE | 675.16 | 241.20 | 1693.70 |
| **F-4** | 50+66.66 | 83.76 | NONE | 3659.65 | 744.72 | 1043.76 |
| **F-5** | 50 | 30.26 | 385.57 | 801.80 | NONE | NONE |
| **TOTAL** | | 149.07 | 385.57 | 5136.61 | 985.92 | 2737.46 |

### Table 80. Aircraft Attrition, Second Plan F-4 Cost = 12

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 15.99 | 10.77 | 8.28 | 35.04 |
| **F-4** | 32.79 | 28.99 | 21.98 | 83.76 |
| **F-5** | 6.17 | 14.55 | 9.53 | 30.26 |
| **TOTAL** | 54.98 | 54.31 | 39.79 | **149.07** |

### Table 81. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 13

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+0.70 | 35.90 | NONE | 641.64 | 241.20 | 1823.42 |
| **F-4** | 50+59.91 | 80.42 | NONE | 3659.65 | 644.48 | 1043.76 |
| **F-5** | 50 | 26.85 | 373.81 | 801.80 | NONE | NONE |
| **TOTAL** | | 143.18 | 373.81 | 5103.09 | 885.68 | 2867.18 |

### Table 82. Aircraft Attrition, Second Plan F-4 Cost = 13

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 17.46 | 10.61 | 7.83 | 35.90 |
| **F-4** | 32.79 | 25.64 | 21.98 | 80.42 |
| **F-5** | NONE | 17.31 | 9.53 | 26.85 |
| **TOTAL** | 50.25 | 53.57 | 39.34 | **143.18** |

### Table 83. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 14

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+0 .45 | 35.75 | 67.09 | 557.66 | 241.20 | 1856.73 |
| **F-4** | 50+56.17 | 78.56 | NONE | 3659.65 | 588.89 | 1043.76 |
| **F-5** | 50 | 26.68 | 402.16 | 801.80 | NONE | NONE |
| **TOTAL** | | 141.09 | 469.25 | 5019.11 | 830.09 | 2900.49 |

### Table 84. Aircraft Attrition, Second Plan F-4 Cost = 14

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 17.46 | 10.45 | 7.83 | 35.75 |
| **F-4** | 32.79 | 23.79 | 21.98 | 78.56 |
| **F-5** | NONE | 17.15 | 9.53 | 26.68 |
| **TOTAL** | 50.25 | 51.40 | 39.34 | **141.00** |

### Table 85. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 15

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+0 .45 | 36.38 | 506.53 | NONE | 241.20 | 2311.49 |
| **F-4** | 50+56.17 | 73.46 | NONE | 1215.67 | 661.39 | 1531.10 |
| **F-5** | 50 | 26.86 | 375.89 | 801.80 | NONE | NONE |
| **TOTAL** | | 136.71 | 882.42 | 2017.47 | 902.59 | 3842.59 |

### Table 86. Aircraft Attrition, Second Plan F-4 Cost = 15

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 19.06 | 9.48 | 7.83 | 36.38 |
| **F-4** | 24.06 | 27.42 | 21.98 | 73.46 |
| **F-5** | NONE | 17.32 | 9.53 | 26.86 |
| **TOTAL** | 50.25 | 51.40 | 39.34 | 136.71 |

**Table 87. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 16**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1D | 50+ 0.45 | 37.78 | 506.53 | NONE | 241.20 | 2487.97 |
| F-4 | 50+56.17 | 68.18 | NONE | 1215.67 | 588.89 | 1494.78 |
| F-5 | 50 | 26.68 | 402.16 | 801.80 | NONE | NONE |
| TOTAL | | 132.65 | 908.69 | 2017.47 | 830.09 | 3982.75 |

**Table 88. Aircraft Attrition, Second Plan F-4 Cost = 16**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1D | 20.59 | 9.35 | 7.83 | 37.78 |
| F-4 | 19.35 | 26.85 | 21.98 | 68.18 |
| F-5 | NONE | 17.15 | 9.53 | 26.68 |
| TOTAL | 39.94 | 53.36 | 39.34 | **132.65** |

**Table 89. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 27**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| A/C-1D | 50+22.31 | 55.21 | 506.53 | NONE | 241.20 | 3690.21 |
| F-4 | 50+4.83 | 39.67 | 1205.63 | 1013.06 | 365.40 | 609.58 |
| F-5 | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| TOTAL | | 116.77 | 2332.51 | 1374.86 | 606.6 | 4299.79 |

**Table 90. Aircraft Attrition, Second Plan F-4 Cost = 27**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| A/C-1D | 24.23 | 12.21 | 18.76 | 55.21 |
| F-4 | 8.14 | 11.58 | 19.95 | 39.67 |
| F-5 | NONE | 21.88 | NONE | 21.88 |
| TOTAL | 32.37 | 45.67 | 38.71 | **116.77** |

**Table 91. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 28**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+20.62 | 53.56 | 506.53 | NONE | 241.20 | 3511.58 |
| **F-4** | 50+6.47 | 41.52 | 1149.54 | 1215.67 | 365.40 | 609.58 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 116.97 | 2276.42 | 1577.47 | 606.6 | 4121.16 |

**Table 92. Aircraft Attrition, Second Plan F-4 Cost = 28**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 24.23 | 12.50 | 16.81 | 53.56 |
| **F-4** | 8.14 | 11.40 | 21.98 | 41.52 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 32.37 | 45.79 | 38.79 | **116.97** |

**Table 93. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 29**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+19.78 | 53.16 | 506.53 | NONE | 241.20 | 3489.74 |
| **F-4** | 50+7.11 | 41.76 | 1428.89 | 1215.67 | 365.40 | 609.58 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 116.81 | 2555.77 | 1577.47 | 606.6 | 4099.32 |

**Table 94. Aircraft Attrition, Second Plan F-4 Cost = 29**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 24.23 | 12.10 | 16.81 | 53.16 |
| **F-4** | 8.14 | 11.64 | 21.98 | 41.76 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 32.37 | 45.63 | 38.79 | **116.81** |

**Table 95. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 30**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+18.76 | 52.67 | 506.53 | NONE | 241.20 | 3463.06 |
| **F-4** | 50+7.90 | 42.06 | 1319.99 | 1215.67 | 365.40 | 609.58 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 116.61 | 2446.87 | 1577.47 | 606.6 | 4072.64 |

**Table 96. Aircraft Attrition, Second Plan F-4 Cost = 30**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 24.23 | 11.61 | 16.81 | 52.67 |
| **F-4** | 8.14 | 11.93 | 21.98 | 42.06 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 32.37 | 45.43 | 38.79 | **116.61** |

**Table 97. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 31**

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+17.48 | 52.06 | 506.53 | NONE | 241.20 | 3429.76 |
| **F-4** | 50+8.88 | 42.42 | 1436.99 | 1215.67 | 365.40 | 609.58 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 116.37 | 2563.87 | 1577.47 | 606.6 | 4039.34 |

**Table 98. Aircraft Attrition, Second Plan F-4 Cost = 31**

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 24.23 | 11.00 | 16.81 | 52.06 |
| **F-4** | 8.14 | 12.30 | 21.98 | 42.42 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 32.37 | 45.18 | 38.79 | **116.38** |

### Table 99. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 32

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **F-16** | 50+15.83 | 51.27 | 506.53 | NONE | 241.20 | 3386.99 |
| **F-4** | 50+10.15 | 42.89 | 1587.22 | 1215.67 | 365.40 | 609.58 |
| **F-5** | 50 | 21.88 | 620.35 | 361.80 | NONE | NONE |
| **TOTAL** | | 116.05 | 2714.1 | 1577.47 | 606.6 | 3996.57 |

### Table 100. Aircraft Attrition, Second Plan F-4 Cost = 32

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 24.23 | 10.22 | 16.81 | 51.27 |
| **F-4** | 8.14 | 12.77 | 21.98 | 42.89 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 32.37 | 44.88 | 38.79 | **116.05** |

### Table 101. Aircraft-Weapon Allocations, Second Plan F-4 Cost = 33

| Aircraft | Total Usage | Total Attrition | Mk-82 | Mk-84 | Durandal | Maverick |
|---|---|---|---|---|---|---|
| **A/C-1D** | 50+14.14 | 50.50 | 506.53 | 4.63 | 241.20 | 3341.24 |
| **F-4** | 50+11.38 | 43.28 | 1753.42 | 1215.67 | 364.37 | 605.54 |
| **F-5** | 50 | 21.88 | 621.35 | 360.85 | NONE | NONE |
| **TOTAL** | | 115.67 | 2881.31 | 1581.16 | 605.57 | 3946.79 |

### Table 102. Aircraft Attrition, Second Plan F-4 Cost = 33

| Aircraft Types | Phase 1 | Phase 2 | Phase 3 | Total Attrition |
|---|---|---|---|---|
| **A/C-1D** | 24.23 | 9.38 | 16.88 | 50.50 |
| **F-4** | 8.14 | 13.25 | 21.88 | 43.28 |
| **F-5** | NONE | 21.88 | NONE | 21.88 |
| **TOTAL** | 32.37 | 44.52 | 38.76 | **115.67** |

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## VITA

1 Lt Plt Hakan BAL was born in TURKEY. Upon graduation from MALTEPE Military High School, Izmir, in 1990 he entered the Turkish Air Force Academy. Lt. BAL graduated from the Academy as a Second Lieutenant in 1994.

After graduation from the Pilot Training School at Cigli AFB, Izmir, Lt. BAL was assigned to War Readiness Training School at Konya AFB. In 1996 he was assigned to the ONCEL Training Squadron where he was a trainee in the F-16 C/D Block 30. A year later, Lt BAL was assigned to the 191st Fighter Squadron as a wingman where he flew F-16 Block 50. During the recent NATO operation, he was assigned to Ghedi, Italy, where he flew combat missions against Serbia.

After his return from Italy, Lt BAL was selected for the Postgraduate Education Program. He entered the Graduate School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, in 1999 with a total of 900 flying hours. After graduation, he will return to the 191. Fighter Squadron.

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The purpose of this research is to develop a mathematical model which will aid the decision-makers of a moderately-sized NATO country to develop their future force structure composition. As the number of alternatives grows, and as the consequences become more important and more uncertain, the force structuring decision becomes increasingly difficult. The valuable lessons of past experience cannot be ignored. However, when one considers the high rotation rates of most countries' air forces, the rapid change in technology and the vast array of options available, even the most experienced leaders need some assistance. Hence, decision support tools are needed to aid senior-level decision processes. This research addresses a quantitative analytical support tool for senior decision-makers to use for future procurement decisions.

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